



NCL Method ITA-9.1

Phagocytosis Assay

Nanotechnology Characterization Laboratory
Frederick National Laboratory for Cancer Research
Leidos Biomedical Research, Inc.
Frederick, MD 21702
(301) 846-6939
ncl@mail.nih.gov
[http://www.ncl.cancer.gov](https://www.ncl.cancer.gov)



This protocol assumes an intermediate level of scientific competency with regard to techniques, instrumentation, and safety procedures. Rudimentary assay details have been omitted for the sake of brevity.

Method written by:

Timothy M. Potter¹,

Edward Cedrone¹,

Barry W. Neun¹

Marina A. Dobrovolskaia^{1,*}

1 - Nanotechnology Characterization Lab., Frederick National Laboratory for Cancer Research,
Frederick, MD 21702

*- address correspondence to: marina@mail.nih.gov

1. Introduction

This document describes a protocol for evaluation of nanoparticle internalization by phagocytic cells, where the foreign substances are isolated via a cell membrane enclosure and degraded by the phagolysosome. Phagocytosis is a receptor mediated endocytosis specific to the phagocytic cells, e.g. cells of the mononuclear phagocytic system (MPS). Phagocytosis is an active process and requires actin polymerization. There are four main receptors which mediate phagocytic uptake. Phagocytosis via three of these receptors (complement receptor (CR), FcγR receptor, and mannose receptor (MR)) is accompanied by inflammatory reactions (cytokine secretion). Phagocytosis via the fourth receptor (scavenger receptor (SR)) is not accompanied by inflammatory responses (1-5).

2. Principles and limitation

This assay utilizes a luminescent-based approach in which nanoparticles are incubated with HL-60 promyelocytic cells, and the phagocytic activity is visualized with luminol. Luminol is a dye which is not luminescent unless exposed to the low pH of the phagolysosome.

This protocol may not be applicable for certain types of nanomaterials. For example, nanoparticles with fluorescent capabilities such as quantum dots may be studied using confocal microscopy or flow cytometry. Modification(s) of the current procedure and or changes in detection dye may be required for particles that demonstrate interference with luminol-dependent chemiluminescence.

3. Reagents, Materials, Cell Lines, and Equipment

Note: The NCL does not endorse any of the suppliers listed below; these reagents were used in the development of the protocol and their inclusion is for informational purposes only. Equivalent supplies from alternate vendors can be substituted. Please note that suppliers may undergo a name change due to a variety of factors. Brands and part numbers typically remain consistent but may also change over time.

- 3.1 Reagents
 - 3.1.1 Phosphate buffered saline (PBS) (GE Life Sciences, Hyclone, SH30256.01)
 - 3.1.2 Zymosan A, (Sigma-Aldrich, Z4250)
 - 3.1.3 Fetal bovine serum (FBS) (GE Life Sciences, Hyclone, SH30070.03)
 - 3.1.4 RPMI-1640 (GE Life Sciences, HyClone, SH30096.01)
 - 3.1.5 Penicillin streptomycin solution (GE Life Sciences, Hyclone, SV30010)
 - 3.1.6 Trypan Blue solution (Gibco, 15250-061)
 - 3.1.7 Human AB serum or plasma pooled from at least three donors.
 - 3.1.8 Luminol (Sigma-Aldrich, 123072)
- 3.2 Materials
 - 3.2.1 Pipettes covering range from 0.05 to 10 mL
 - 3.2.2 Flat bottom 96-well white luminescence plates
 - 3.2.3 Polypropylene tubes, 50 and 15 mL
- 3.3 Cell Lines
 - 3.3.1 HL-60 promyelocytic cells (ATCC, CCL-240)
- 3.4 Equipment
 - 3.4.1 Centrifuge capable of operating at 400 x g and 2000 x g
 - 3.4.2 Refrigerator, 2-8°C
 - 3.4.3 Freezer, -20°C
 - 3.4.4 Cell culture incubator with 5% CO₂ and 95% humidity.
 - 3.4.5 Biohazard safety cabinet approved for level II handling of biological material
 - 3.4.6 Inverted microscope
 - 3.4.7 Vortex
 - 3.4.8 Hemocytometer
 - 3.4.9 Plate reader capable of working in luminescence mode

Note: The plates used for this assay have a solid white bottom, therefore the plate should be read from the top. Depending on the type of the plate reader one may need to use a plate adaptor to provide optimal condition for the top read.

 - 3.4.10 Warm gel-pack

Note: this material is optional and may be omitted. It is used to keep the plate warm for optimal phagocytosis. However, if it takes longer than 2 minutes to transfer the plate to the plate reader after addition of all reagents, the phagocytosis process will begin before one starts to analyze the plate on the plate reader.

4. Reagent and Control Preparation

4.1 Complete RPMI-1640 medium

The complete RPMI medium should contain the following reagents:

20% FBS (heat inactivated)

4 mM L-glutamine

100 U/mL penicillin

100 µg/mL streptomycin sulfate

Store at 2-8°C protected from light for no longer than 1 month. Before use, warm in a water bath.

4.2 Zymosan A Stock

Prepare Zymosan A stock at final concentration of 2 mg/mL in PBS. Use freshly prepared.

4.3 Positive control (read section 5 to determine which approach to use)

Approach A - Combine Zymosan A stock and human AB serum or plasma. Use 1 mL of serum/plasma per each 0.5 mL of zymosan A stock. Incubate Zymosan A with serum/plasma for 30 minutes at 37°C. Wash Zymosan A particles two times with PBS (use 1 mL of PBS per each 0.5 mL of original zymosan stock and a centrifuge setting of 2000 x g for 2 min) and re-suspend in PBS to a final concentration of 2 mg/mL.

Approach B – Reconstitute Zymosan A in 20% human AB serum/plasma in PBS to a final concentration of 2 mg/mL.

4.4 Negative Control

Use PBS as a negative control. Process this control the same way as test nanoparticle.

4.5 Heat-inactivated fetal bovine serum

Thaw a bottle of FBS at room temperature, or overnight at 2-8°C and allow to equilibrate to room temperature. Incubate 30 minutes at 56°C in a water bath, mixing every 5 minutes. Single use aliquots may be stored at 2-8°C for up to one month or at a nominal temperature of -20°C indefinitely.

4.6 Luminol Stock (10 mM in DMSO)

Dissolve luminol in DMSO to a final concentration of 10 mM, e.g. dissolve 17.7 mg of luminal in 10 mL of DMSO. Prepare single use aliquots and store at -20°C; protect from light.

4.7 Luminol Working Solution (250 µM in PBS).

On the day of the experiment, thaw an aliquot of luminol stock solution and dilute with PBS to a final concentration of 250 µM, e.g. add 250 µL of 10 mM stock into 9.750 mL of PBS. Protect from light. Discard unused portion.

4.8 Vehicle Control

Vehicle control is the buffer or media used to formulate test nanomaterials. Common excipients used in nanoformulations are trehalose, sucrose, and albumin. However, other reagents and materials are also used alone or in combination. Vehicle control should match formulation buffer of the test-nanomaterial by both composition and concentration. This control can be skipped if nanoparticles are stored in PBS.

5. Preparation of Study Samples

This assay requires 2 mL of nanoparticles at 3x the highest test concentration dissolved/resuspended in PBS. The concentration is selected based on the plasma concentration of the nanoparticle at the intended therapeutic dose. For the purpose of this protocol this concentration is called “theoretical plasma concentration”. Considerations for estimating theoretical plasma concentration were reviewed elsewhere (6) and are summarized in Box 1 below.

Box 1. Example Calculation of Nanoparticle concentration for In Vitro Test

In this example, we assume the mouse dose is known to be 123 mg/kg.

$$\text{human dose} = \frac{\text{mouse dose}}{12.3} = \frac{123 \frac{\text{mg}}{\text{kg}}}{12.3} = 10 \text{ mg/kg}$$

Blood volume constitutes approximately 8% of body weight, (e.g. a 70 kg human has approximately 5.6 L (8% of 70) of blood). This allows us to get a very rough estimation of what the maximum blood concentration may be.

$$\begin{aligned} \text{in vitro concentration}_{\text{human matrix}} &= \frac{\text{human dose}}{\text{human blood volume}} = \frac{70 \text{ kg} \times 10 \frac{\text{mg}}{\text{kg}}}{5.6 \text{ L}} \\ &= \frac{700 \text{ mg}}{5.6 \text{ L}} = 0.125 \text{ mg/mL} \end{aligned}$$

The assay will evaluate 4 concentrations: 10 X (or when feasible 100X, 30X or 5X) of the theoretical plasma concentration, theoretical plasma concentration and two 1: 5 serial dilutions of the theoretical plasma concentration. When the intended therapeutic concentration is unknown, the highest final concentration is 1 mg/mL or the highest reasonably achievable concentration. For example, if the final theoretical plasma concentration to be tested is 0.2 mg/mL, then a stock of 6 mg/mL will be prepared and diluted 10-fold (0.6 mg/mL), followed by two 1: 5 serial dilutions (0.12 and 0.024 mg/mL). When 100 µL of each of these samples are combined in a culture plate well with 100 µL of luminol and 100 µL of cells the final concentrations of nanoparticles are 0.008, 0.04, 0.2, 2mg/mL. Each nanoparticle concentration is plated 3 times.

Human AB serum or plasma and opsonization procedure used for the positive control is also used to opsonize the nanoparticles. The nanoparticle to Serum/Plasma volume ratio and incubation conditions are the same as described for the positive control in section 4.3.

If centrifugation to separate nanoparticles from bulk plasma is possible, Approach A (described in section 4.3) is used to prepare both the positive control and nanoparticles. However, when centrifugation is not applicable to the nanoparticles, both particles and positive control are prepared according to Approach B (described in section 4.3).

Note: If approach B is used, nanoparticle opsonization can be performed either using the stock nanoparticle or each tested concentration. When nanoparticle stock is used for opsonization, further dilutions of this stock should be performed in the medium containing serum or plasma.

6. Cell Preparation

HL-60 is a non-adherent promyelocytic cell line derived by S.J. Collins, et al. from a patient with acute promyelocytic leukemia (5). Cultures can be maintained by the addition of fresh medium or replacement of medium. Alternatively, cultures can be established by centrifugation with subsequent resuspension at 1×10^5 viable cells/mL. **Do not allow cell concentration to exceed 1×10^6 cells/mL.** Maintain cell density between 1×10^5 and 1×10^6 viable cells/mL. On the day of the experiment, count cells using trypan blue. If the cell viability is $\geq 90\%$ proceed to the next step.

7. Experimental Procedure

- 7.1 Turn on plate reader, allowing it to warm up to 37°C . Place an empty white 96-well test plate inside the plate reader chamber, allowing it to warm to 37°C as well. Set up the instrumental parameters.
- 7.2 Adjust cell concentration to 1×10^7 cells/mL by spinning cell suspension down and reconstituting in complete medium (refer to section 4.1 for details). Keep at room temperature.
- 7.3 Add 100 μL of controls and test-nanoparticles in PBS to appropriate wells of the pre-warmed test plate. Prepare three duplicate wells for each sample and two duplicate wells for positive and negative control.
Note: Always leave duplicate wells for each of the following controls: 1) luminol only control (no cells); 2) nanoparticles only (no cells); and 3) nanoparticles plus luminol (no cells). See Appendix for an example plate map.
- 7.4 Add 100 μL working luminol solution in PBS to each sample- containing well. Do not forget to prepare two “luminol only” control wells.

Note: keeping the plate warm during sample aliquoting (e.g. using plate warmer or warm gel pack) may be helpful to achieve optimal assay performance and reproducibility.

7.5 Plate 100 µL of cell suspension per well on the 96 well white plate.

7.6 Start kinetic reading on a luminescence plate reader immediately.

Note: plate readers capable of both top and bottom reading may require a plate adaptor for top reads. Check reader user manuals before proceeding with the plate analysis on the plate reader.

8. Calculations

8.1 Using Excel or other relevant software compare area under the curve (AUC) for all samples. Increase in the AUC at least 2-fold above the negative control (baseline) is considered as positive response. Use relevant statistical analysis to compare AUC values for test samples with that of the baseline.

8.2 A percent coefficient of variation is used to control precision and calculated for each control or test sample according to the following formula:

$$\%CV = (SD/Mean) \times 100\%$$

9. Acceptance Criteria

9.1 %CV for each control and test sample should be < 30%.

9.2 Samples demonstrating higher variability should be re-analyzed.

10. References

1. Antonini JM., van Dyke K., ye Z., DeMatteo M., Reasor MJ. Introduction of luminol-dependent chemiluminescence as a method to study silica inflammation in the tissue and phagocytic cells of rat lung. Environ. Health Perspect., 1994, 102(suppl10), 37-42.
2. Gref R., Luck M., Quellec P., et al. Stealth corona-core nanoparticles surface modified by PEG: influences of corona (PEG chain length and surface density) and of the core composition on phagocytic uptake and plasma protein absorption. Colloids and surfaces B: Biointerfaces, 2000, 18: 301-313.

3. Leroux JC., Gravel P., Balant L., et al. Internalization of poly(D,L-lactic acid) nanoparticles by isolated human leukocytes and analysis of plasma proteins absorbed onto particles. J.Biomed.Materials Res., 1994, 28:471-481.
4. Mold C., Gresham HD., DuClos TW. Serum Amyloid P component and C-reactive protein mediate phagocytosis through murine FcγRs. J.Immunol., 2001, 166:1200-1205.
5. Collins SJ, Ruscetti FW, Gallagher RE, Gallo RC. Terminal differentiation of human promyelocytic leukemia cells induced by dimethyl sulfoxide and other polar compounds. Proc Natl Acad Sci U S A. 1978 May;75(5):2458-62.
6. Dobrovolskaia MA, McNeil SE. Understanding the correlation between in vitro and in vivo immunotoxicity tests for nanomedicines. J Control Release. 2013 Dec 10;172(2):456-66

11. Abbreviations


AUC	area under the curve
CV	coefficient of variation
DMSO	dimethyl sulfoxide
FBS	fetal bovine serum
PBS	phosphate buffered saline
RPMI	Roswell Park Memorial Institute
SD	standard deviation
VC	vehicle control

12. Appendix

Example Plate Map

	1	2	3	4	5	6	7	8	9	10	11	12
A	Blank	PC	NC	TS 0.008 mg/mL	TS 0.008 mg/mL	TS 0.008 mg/mL	TS 0.04 mg/mL	TS 0.04 mg/mL	TS 0.04 mg/mL	TS 0.2 mg/mL	TS 0.2 mg/mL	TS 0.2 mg/mL
B	Blank	PC	NC	TS 0.008 mg/mL	TS 0.008 mg/mL	TS 0.008 mg/mL	TS 0.04 mg/mL	TS 0.04 mg/mL	TS 0.04 mg/mL	TS 0.2 mg/mL	TS 0.2 mg/mL	TS 0.2 mg/mL
C	TS 1.0 mg/mL	TS 1.0 mg/mL	TS 1.0 mg/mL	Blank	PC	NC	VC	VC				
D	TS 1.0 mg/mL	TS 1.0 mg/mL	TS 1.0 mg/mL	Blank	PC	NC	VC	VC				
E												
F												
G	Luminol	TS 0.008 mg/mL + Luminol	TS 0.04 mg/mL + Luminol	TS 0.2 mg/mL + Luminol	TS 1.0 mg/mL + Luminol	TS 0.008 mg/mL NO LUMINOL	TS 0.04 mg/mL NO LUMINOL	TS 0.2 mg/mL NO LUMINOL	TS 1.0 mg/mL NO LUMINOL			
H	Luminol	TS 0.008 mg/mL + Luminol	TS 0.04 mg/mL + Luminol	TS 0.2 mg/mL + Luminol	TS 1.0 mg/mL + Luminol	TS 0.008 mg/mL NO LUMINOL	TS 0.04 mg/mL NO LUMINOL	TS 0.2 mg/mL NO LUMINOL	TS 1.0 mg/mL NO LUMINOL			

PC: Positive Control; NC: Negative Control; TS: Test Sample; VC- vehicle control

 No cells