Potential viral pathogenic mechanism for new variant inflammatory bowel disease


Aims: A new form of inflammatory bowel disease (ileocolonic lymphonodular hyperplasia) has been described in a cohort of children with developmental disorder. This study investigates the presence of persistent measles virus in the intestinal tissue of these patients (new variant inflammatory bowel disease) and a series of controls by molecular analysis.

Methods: Formalin fixed, paraffin wax embedded and fresh frozen biopsies from the terminal ileum were examined from affected children and histological normal controls. The measles virus Fusion (F) and Haemagglutinin (H) genes were detected by TaqMan reverse transcription polymerase chain reaction (RT-PCR) and the Nucleocapsid (N) gene by RT in situ PCR. Localisation of the mRNA signal was performed using a specific follicular dendritic cell antibody.

Results: Seventy five of 91 patients with a histologically confirmed diagnosis of ileal lymphonodular hyperplasia and enterocolitis were positive for measles virus in their intestinal tissue compared with five of 70 control patients. Measles virus was identified within the follicular dendritic cells and some lymphocytes in foci of reactive follicular hyperplasia. The copy number of measles virus ranged from one to 300 000 copies/ng total RNA.

Conclusions: The data confirm an association between the presence of measles virus and gut pathology in children with developmental disorder.

MATERIALS AND METHODS

Patients and RNA extraction

All patient samples were provided by the department of gastroenterology, Royal Free Hospital, London, UK. Ileal lymphoid tissues from 91 affected children were examined (median age, 7 years; range, 3–14; 77 boys). Developmentally normal paediatric controls (n = 70; range, 0–17 years; 47 boys) included: 19 children with normal ileal biopsies, 13 children with mild non-specific chronic inflammatory changes, three children with ileal lymphonodular hyperplasia (LNH) investigated for abdominal pain, eight children with Crohn’s disease, one child with ulcerative colitis, and 26 children who had undergone appendicectomy for abdominal pain including appendicitis.

MV positive control material included two cases of SSPE and MV infected Vero cells. Negative control material included uninfected Vero cells, and human tissues, control RNA extracted from Raji cells (Applied Biosystems, Foster City, California, USA) and normal peripheral blood mononuclear cells.

Total RNA was extracted from fresh frozen biopsies, peripheral blood mononuclear cells, and MV infected and uninfected Vero cell lines using the Ultraspec-11 RNA isolation system (Biotecx Laboratories, Houston, Texas, USA). Total RNA was extracted from formalin fixed, paraffin wax embedded tissues using the Purescript® RNA isolation kit (Gentra Systems, Minneapolis, Minnesota, USA).

Abbreviations: AP, alkaline phosphatase; BCIP, 5-bromo-4-chloro-3-indoyl phosphate; DIG, digoxigenin; F, fusion; H, haemagglutinin; IL, interleukin; LNH, lymphonodular hyperplasia; MV, measles virus; N, nucleocapsid; NBT, nitroblue tetrazolium; PCR, polymerase chain reaction; RT, reverse transcription; SSC, saline sodium citrate; SSPE, subacute sclerosing panencephalitis; TH1, T helper cell type 1

*These authors share first authorship.
Table 1 Measles virus primer and probe sequences

<table>
<thead>
<tr>
<th>Primer/Probe</th>
<th>Sequence 5’–3’</th>
<th>Amplicon size</th>
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<tr>
<td>N1 forward</td>
<td>5’TCA GTA GAG CCG TTC GAC CC 3’</td>
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<tr>
<td>N1 reverse</td>
<td>5’GCC CGG TGT TCT CGT TAG CT 3’</td>
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<tr>
<td>N2 forward</td>
<td>5’GAG TCG AGG AGA AGC CGG GG 3’</td>
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<tr>
<td>N2 reverse</td>
<td>5’GCT GGA CTC CGA TGC AGT GT 3’</td>
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<tr>
<td>H1 forward</td>
<td>5’TTC ATG GGG CCG CCA TCT AC 3’</td>
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</tr>
<tr>
<td>H1 reverse</td>
<td>5’CTC TGA GGT GTC CTC AGG CC 3’</td>
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<tr>
<td>H2 forward</td>
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<tr>
<td>H2 reverse</td>
<td>5’AAC GTG GTG TCG GTA TCA ATG GC 3’</td>
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</tr>
<tr>
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<td>F1 reverse</td>
<td>5’TGG GTC ATT GTA TTA ATG GCA 3’</td>
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<tr>
<td>F2 forward</td>
<td>5’CCC ACC GGT CAA ATC CAT 5’</td>
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<td>N1 probe</td>
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<td>H1 probe</td>
<td>5’CCG CAG AGA TTC AAT AAG GGC TCA GCA C 3’</td>
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<td>F1 probe</td>
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<tr>
<td>GAPDH probe</td>
<td>5’CGG ACT CTT GCC CTT CCA AC 3’</td>
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Measles virus N gene primers and probes were designed based on the following Genbank sequence entries (accession numbers): X16565, S58435, NC_002494, NC_002496, X01999, U03661, U03658, and U03656. Measles virus H gene primers and probes were designed based on the following GenBank sequence entries: X16565, U03649, U03654, U03669, U03660, U03671, U03667, 280793, AF0045204, Z66517, and Z80816. Measles virus F gene primers and probes were designed based on the following Genbank sequence entries: X16565, U03655, U03666, U03648, U03662, U08146, U03657, U03651, U03659, AJ133108, X16567.

Solution phase RT-PCR
Polymerase chain reaction (PCR) primers and probes to conserved regions of the MV Nucleocapsid (N), Haemagglutinin (H), and Fusion (F) genes were designed using Primer Express Software Version 1.5 (ABI Prism; Applied Biosystems). The specificity of selected sequences was checked using the NCBI Blast program (www.ncbi.nlm.nih.gov/blast). Table 1 shows the MV primer and probe sequences, amplicon sizes, and GenBank accession numbers for designing PCR primers and oligonucleotide probes. In some instances primer sets overlap with each other (for example, the sequence of amplicon N1 overlaps partially with the N2 PCR amplicon). For in situ PCR, oligonucleotide probes were modified at the 5’ end by the addition of a biotin moiety and for Southern blot analysis probes were labelled at the 3’ end with digoxigenin. For TaqMan quantitative reverse transcription PCR (RT-PCR), probes were dual labelled with the fluorescent molecule FAM at the 5’ end and the quencher TAMRA at the 3’ end.

Purified MV RNA (HU2) was used as a positive control to optimise PCR assays. The following optimal reaction conditions were used for each 25 pl reaction: 0.4mM dNTPs, 0.4µM forward and reverse primers, 2.5mM magnesium acetate, 3 U rTth DNA polymerase, 0.01 U AmpErase, and 1× EZ buffer. The EZ buffer consisted of 50mM bicine, 125mM potassium acetate, 40% (wt/vol) glycerol (pH 8.2) (Applied Biosystems); EZ buffer. The ×10 reaction mixture was prepared in a dedicated facility in a class 2 laminar flow bench hood using dedicated pipettors and aerosol resistant pipette tips. Template

Southern blot analysis
To confirm reaction specificity, solution phase RT-PCR was performed, as described above, on four affected children positive for MV by TaqMan RT-PCR (see below). MV F and H gene amplicons from MV infected Vero cells, SSPE brain, and ileal lymphoid tissues from four affected children, together with a no template control, were examined by Southern blotting’ using sequence specific probes (Table 1). MV specific oligonucleotide probes were labelled at the 3’ end with digoxigenin using a DIG oligonucleotide 3’ end labelling kit (Roche Molecular Biochemicals, Mannheim, Germany), hybridised to the Southern blot at 50°C in 5x saline sodium citrate (SSC) with 0.2% sodium dodecyl sulfate for one hour, washed once in 5x SSC at 50°C for 10 minutes, once in 2× SSC at room temperature for 10 minutes, and once in 0.2× SSC at room temperature for 10 minutes. Hybrids were detected using the DIG luminescent detection kit (Roche Molecular Biochemicals).

Figure 1 Gel electrophoresis of measles virus cDNA amplicons (HU2 control measles virus RNA) amplified under optimised reaction conditions. Lanes 1 and 10, 100 base pair DNA ladder (Gibco-BRL, Paisley, Scotland, UK). Lanes 2 and 3, Fusion (F) gene cDNA amplicons for two different F gene primer sets. Lanes 4 and 5, Nucleocapsid (N) gene cDNA amplicons for two different N gene primer sets. Lanes 6 and 7, Haemagglutinin (H) gene cDNA amplicons for two different H gene primer sets. Lanes 8, positive control human pyruvate dehydrogenase PCR product. Lane 9, no template control for lane 2.

50°C in 5x saline sodium citrate (SSC) with 0.2% sodium dodecyl sulfate for one hour, washed once in 5x SSC at 50°C for 10 minutes, once in 2× SSC at room temperature for 10 minutes, and once in 0.2× SSC at room temperature for 10 minutes. Hybrids were detected using the DIG luminescent detection kit (Roche Molecular Biochemicals).

TaqMan RT-PCR
Real time quantitative RT-PCR based on the 5’ nuclease assay was performed on an ABI 7700 Sequence detector (Applied Biosystems). Sequence specific PCR primers and TaqMan probes were designed using Primer Express software as described above. All quantitative PCRs were prepared in a dedicated facility in a class 2 laminar flow bench hood using dedicated pipettors and aerosol resistant pipette tips. Template
RNA was prepared and added to the PCR mastermix in a separate facility.

TaqMan RT-PCR was performed using EZ TaqMan RT PCR reagents according to the manufacturer’s instructions (Applied Biosystems). RT-PCR reactions were performed in duplicate under the following conditions for each 25 µl reaction: 1× EZ buffer, 3 mM MnOAc₂, 200 nmol of each primer, 100 nmol of TaqMan probe, 0.01 U of AmpErase, 0.1 U of rTth polymerase, and 3 µl (5–50 ng) of total RNA. The thermal cycling conditions on the 7700 were as follows: 50°C for two minutes, 58°C for 30 minutes, 95°C for five minutes, followed by 40 cycles of 94°C for 20 seconds and 60°C for one minute.

Controls for TaqMan RT-PCR included the following: no template control (water added as template), no amplification control (omission of rTth polymerase), irrelevant target primers and specific TaqMan probe (human papillomavirus 16, human herpes virus 8 primers), probe only control (omit PCR primers), human RNA control, spiked RNA control, and asymmetric TaqMan PCR (TaqMan PCR with one or other primer and specific TaqMan probe).

A gene dosage correction was carried out using glyceraldehyde phosphate dehydrogenase as a housekeeping gene. Measles virus quantitative TaqMan RT-PCR was performed by generating standard curves for the F and H genes. Taqman RT-PCR standards were generated by cloning the F and H gene specific PCR products into a vector using the TOPO TA cloning® system (Invitrogen, Groningen, the Netherlands), according to the manufacturer’s instructions. Plasmids containing the PCR

**Figure 2**  
(A) Agarose gel electrophoresis of measles virus Fusion (F) gene and haemagglutinin (H) gene reverse transcription polymerase chain reaction (RT-PCR) amplicons generated using RNA extracted from fresh frozen terminal ileum biopsies from affected children and subacute sclerosing panencephalitis (SSPE) brain tissue and measles infected Vero cells. M denotes 100 base pair molecular weight marker; lanes 1–6 show F gene PCR amplicons from the following RNA samples: measles infected Vero cells, SSPE brain, affected children 1–4, respectively; lane 7, no template control. Lanes 8–14 show H gene PCR amplicons generated from RNA samples in the same order as above. For one sample, RT-PCR for the F gene failed (lane 5). (B) Southern blot of the agarose gel described in (A) probed with a digoxigenin (DIG) labelled F gene specific probe as described in materials and methods. (C) Southern blot of the agarose gel described in (A) stripped and reprobed with a DIG labelled H gene specific probe.
inserts were then in vitro transcribed into cRNA using the Riboprobe® in vitro transcription system (Promega, Madison, Wisconsin, USA). Serial dilutions of this cRNA were used to generate standard curves.

**RT in situ PCR**

RT in situ PCR facilitates low copy gene detection and permits cellular localisation within tissues, with a reported sensitivity of one viral genome copy/cell. Reaction optimisation experiments were initially carried out with a single stranded biotinylated oligonucleotide probe for the detection of the measles virus nucleocapsid (N) gene in infected Vero cells. Optimal cytoplasmic staining is achieved in (A) (1 µg/ml), higher probe concentrations in panels (B) (1.5 µg/ml) and (C) (2 µg/ml) showed increasing non-specific nuclear staining.

Controls for RT in situ PCR included the following: MV infected and uninfected Vero cells, a mixed population of infected and uninfected Vero cells, MV N gene primers and an irrelevant probe (nonsense pyruvate dehydrogenase probe), and irrelevant primers and N gene specific probe. Hybridisation control experiments were performed using a histone mRNA probe. Other control experiments included RNase digestion of MV infected Vero cells before RT in situ PCR.

**Combined RT in situ PCR and immunohistochemistry**

To examine MV signal localisation, RT in situ PCR for the MV N gene was performed as described above on tissue sections following immunohistochemistry using the follicular dendritic cell CNA 42 monoclonal antibody (Dako). For in situ hybridisation a 5’ biotin labelled oligonucleotide probe was used as above.

The MV hybridisation signal was developed with horseradish peroxidase and aminoethyl carbazole (AEC; Vector Laboratories, Burlingame, California, USA), and the dendritic cell signal was developed using a three step detection method with AP (Dako) and NBT and BCIP (Roche Molecular Biochemicals) as substrate.

**Ethical approval**

Approval for these studies was obtained from the ethical practices committee of the Royal Free, Hampstead, NHS Trust. Fully informed, written parental consent was obtained from all trust patients including controls.

**RESULTS**

Overall, 75 of 91 affected children had MV RNA in their ileal lymphoid tissue compared with five of 70 in the control patient cohort (Fisher exact test, p < 0.0001; Analyse-it Software, General 1.62).

A total of six different PCR primer sets were optimised by solution phase RT-PCR to amplify the MV F, H, and N genes from RNA extracted from MV infected Vero cells (fig 1).

The specificity of the primer/probe sets to detect MV F and H genes was established using RNA extracted from: (1) cryopreserved ileal biopsy material from four affected children, (2) SSPE brain, and (3) MV infected Vero cells (fig 2A). All four patient samples were positive for MV F and H genes by TaqMan RT-PCR. Amplicon specificity was confirmed by Southern blot analysis using F and H gene specific probes (fig 2B,C). No template controls run in parallel were negative.

Seventy of 91 affected children were positive for MV compared with four of 70 controls as analysed by TaqMan RT-PCR (table 2). MV copy number in positive biopsies was generally low, but ranged from 1 to 3 × 10^5 copies of MV/ng of total RNA. Of the paediatric control group, MV was not detected in normal children or children with isolated ileal LNH. However, four of 26 appendicectomy samples harboured the MV genome (table 2).

<table>
<thead>
<tr>
<th>Table 2 Summary of TaqMan RT-PCR and RT in situ PCR results</th>
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<tbody>
<tr>
<td><strong>Patient</strong></td>
</tr>
<tr>
<td>-------------</td>
</tr>
<tr>
<td>Affected patients</td>
</tr>
<tr>
<td>Controls (Normal controls)</td>
</tr>
<tr>
<td>Mild non-specific changes</td>
</tr>
<tr>
<td>Lymphonular hyperplasia</td>
</tr>
<tr>
<td>Appendicatomies</td>
</tr>
<tr>
<td>Ulcerative colitis</td>
</tr>
<tr>
<td>Crohn’s disease</td>
</tr>
<tr>
<td>Total number of patients tested in parentheses. NT not tested, RT-PCR, reverse transcription polymerase chain reaction</td>
</tr>
</tbody>
</table>

Controls for RT in situ PCR included the following: MV infected and uninfected Vero cells, a mixed population of infected and uninfected Vero cells, MV N gene primers and an irrelevant probe (nonsense pyruvate dehydrogenase probe), and irrelevant primers and N gene specific probe. Hybridisation control experiments were performed using a histone mRNA probe. Other control experiments included RNase digestion of MV infected Vero cells before RT in situ PCR.
RT in situ PCR optimisation experiments were performed as described (fig 3). A probe concentration of 1 µg/ml yielded optimal signals and was used in subsequent experiments.

In MV infected Vero cells, MV amplicons were identified as a cytoplasmic signal (fig 3). In SSPE brain material, discrete, intense foci of MV amplicons were detected in grey matter using RT in situ PCR (fig 4A). Signal was not detected in similarly processed normal brain, or when irrelevant PCR primers were used on sections of SSPE brain (fig 4B).

Of the 57 tissue biopsies from affected children, 42 were positive for the MV N gene by RT in situ PCR and amplicons could be detected in serial sections of ileal biopsies. Four samples were inconclusive for the presence of MV because of high background staining, and 11 biopsies were negative for MV of the control group, one of five children with histologically normal small and large bowel mucosa had detectable MV N gene RNA, present in a distribution that was identical to that seen in biopsies from affected children (table 2). MV amplicon localised to reactive follicle centres, and was associated with cells possessing dendritic processes (fig 4C, E) and some lymphocytes (fig 4F). No MV signal was seen in serial control sections where irrelevant PCR primers were used (fig 4D). Additional RT in situ PCR control experiments were performed on measles infected Vero cells. No signal was obtained on MV infected Vero cells after RNase digestion (fig 5).

Overall, 91 biopsies have been examined, 56 of which were analysed by a combination of in cell RT-PCR (MV N gene) and TaqMan RT-PCR. Thirty seven of these biopsies were positive for MV and five were negative for MV using both techniques, six were positive by TaqMan RT-PCR but negative by in situ PCR, and five were positive by in situ PCR only (table 2).

**DISCUSSION**

We describe an association between persistent MV infection and ileocolonic lymphonodular hyperplasia and ileocolitis in children with developmental disorder. The molecular data indicate the presence of MV genomes in 75 of 91 affected children with the disorder compared with five of 70 control children. In addition, there appears to be a strong segregation of
the disease phenotype with male children, in keeping with the reported male predominance of the developmental disorder.

MV was not detected in three children with isolated LNHI or in biopsies from normal children. Of the 26 children who underwent appendicectomy, only four harboured MV RNA. The presence of measles virus in the intestine of a small minority of apparently healthy children is not surprising in light of the finding of Warthin-Finkeldey giant cells in inflamed appendices in children with measles infection. However, the prevalence of persistent MV infection in the general population is not known and warrants further investigation.

MV was predominantly detected in dendritic cells in reactive follicular hyperplastic centres in ileal biopsies from affected children (fig 4C,E), but was also identified in mature lymphocytes in these hyperplastic areas (fig 4F). This result indicates a possible interaction between MV and the immune response in the pathogenesis of ileocolitis in these children. MV may be a potential “immunological trigger” in the pathogenesis of lymphoid hyperplasia and ileocolitis. Potential initiators for this type of immunological response are dendritic cells. Dendritic cells capture and process viral antigens in the periphery, express costimulatory molecules, and serve as vehicles for viral antigens to the mediators of immunity (B and T cells) in lymphoid tissue. As a result, cytokines are released and initiate an immune response.

MV localisation was demonstrated in tissue biopsies by RT in situ PCR and combined immunohistochemistry. The signal was a fibrillary character, and appeared to associate with the dendritic cell matrix confirmed by immunohistochemical staining using a specific CNA 42 antibody (fig 4E).

The presence of MV antigen in follicular dendritic cells may reflect a transient stage in the progression from latent to persistent MV infection. The hypothetical parallel with HIV infection is interesting: HIV, like measles virus, potentially disrupts cellular immunity, and induces follicular hyperplasia and lymphadenopathy in the early stage of infection. This is associated with expansion of the follicular dendritic cell network and trapping of HIV within germinal centres.

During the early latent phase of infection, HIV antigens are detectable upon the surface of follicular dendritic cells in a pattern similar to that reported here for MV. Such a location may favour the induction of immunological tolerance and failure of viral clearance. The mechanisms by which MV, immunological abnormalities, and chronic intestinal pathology may be linked are currently not known. Precedents for delayed intestinal and immunological sequelae to MV exposure include chronic immunodeficiency, diarrhoeal disease, and death following early natural measles exposure. Natural measles virus infection induces an initial T helper cell type 1 (Th1) response and protective cytotoxic immunity (characterised by the classic measles rash and gastrointestinal upset), followed by a prolonged Th2 response with antibody production. In most individuals, this leads to lifelong immunity without delayed pathological sequelae. Nonetheless, immune activation during the measles attack is set against a profound reduction in non-specific cellular immune responsiveness, reflecting the potent immunosuppressive properties of MV. Recent studies suggest that this may be achieved through impaired interleukin 12 (IL-12) production by infected dendritic cells, and blocking of IL-2 receptor expression by activated T cells. In such circumstances, impaired Th1 immunity, with a shift towards a dominant Th2 response, might occasionally contribute not only to establishing persistent infection, but also to delayed immunopathology.

“Measles virus may be a potential immunological trigger in the pathogenesis of lymphoid hyperplasia and ileocolitis”

MV was not detected in three children with isolated LNHI or in biopsies from normal children. Of the 26 children who underwent appendicectomy, only four harboured MV RNA. The presence of measles virus in the intestine of a small minority of apparently healthy children is not surprising in light of the finding of Warthin-Finkeldey giant cells in inflamed appendices in children with measles infection. However, the prevalence of persistent MV infection in the general population is not known and warrants further investigation.

**Take home messages**

- Of 91 patients with a histologically confirmed diagnosis of ileal lymphonodular hyperplasia and enterocolitis, 75 were positive for measles virus in their intestinal tissue compared with five of 70 controls.
- Measles virus was found within the follicular dendritic cells and some lymphocytes in foci of reactive follicular hyperplasia.
- These data confirm an association between the presence of measles virus and gut pathology in children with developmental disorder.

These preliminary studies have focused principally on MV. We have not excluded the presence of alternative infections. Viruses may persist elsewhere, or exert a transient effect not requiring subsequent persistence. One such transient risk may be that concurrent exposure to measles and another infection may increase the risk of MV establishing persistent infection: this atypical pattern of exposure has been identified as a risk factor for both SSPE (chicken pox and encephalitogenic enterovirus),

Our study raises many questions—most importantly, does MV play an aetiological role in intestinal inflammation in developmental disorder? The study reports for the first time an association between MV infection and ileocolonic lymphomoid hyperplasia and ileocolitis in children with developmental disorder.

**ACKNOWLEDGEMENTS**

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ECHO

What turns neutrophils on

Insoluble and soluble immune complexes in synovial fluid in rheumatoid arthritis activate neutrophils differently, researchers in Liverpool, UK, have found. Immune complexes and neutrophils are abundant in synovial fluid in rheumatoid arthritis, as are cytokines, which can prime neutrophils making them more responsive. Understanding how immune complexes and neutrophils interact, leading to production of tissue damaging enzymes and oxidants, and the molecular control of the interactions are potential keys to new therapeutic treatments.

Fossati et al. used in vitro chemiluminescence to detect production of oxidants by washed blood neutrophils in their unprimed state or primed with granulocyte-macrophage colony stimulating factor—a cytokine in synovial fluid in rheumatoid arthritis—when incubated with synthetic insoluble or soluble immune complexes. By comparing the reaction kinetics of chemiluminescence with substrates available to the neutrophils either extracellularly or intracellularly and with different specific scavengers of oxidants, they were able to unravel the processes.

Insoluble complexes activated unprimed or primed neutrophils to produce oxidants that remained intracellular whereas soluble complexes reacted only with primed neutrophils but did so rapidly and transiently, the oxidants being secreted. Insoluble complexes also required FcyRIIIb but not FcyRII function whereas soluble complexes required both. In tests to detect granule enzymes insoluble complexes activated secretion with unprimed or primed neutrophils, although the reaction kinetics differed from those for the oxidants. Soluble complexes activated secretion only with primed neutrophils, leading the researchers to conclude that neutrophil activation occurs by different pathways for insoluble or soluble immune complexes and can be significantly affected by cytokines.

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