Infection With Chlamydia pneumoniae Accelerates the Development of Atherosclerosis and Treatment With Azithromycin Prevents It in a Rabbit Model

Joseph B. Muhlestein, MD; Jeffrey L. Anderson, MD; Elizabeth H. Hammond, MD; Liping Zhao, BS; Sanjeev Trehan, MD; Eric P. Schwobe, BS; John F. Carlquist, PhD

Background—Chlamydia pneumoniae infection has been associated with atherosclerosis by serological studies and detection of bacterial antigen within plaque. We sought to evaluate a possible causal role in an animal model.

Methods and Results—Thirty New Zealand White rabbits were given three separate intranasal inoculations of either C pneumoniae (n=20) or saline (n=10) at 3-week intervals and fed chow enriched with a small amount (0.25%) of cholesterol. Immediately after the final inoculation, infected and control rabbits were randomized and begun on a 7-week course of azithromycin or no therapy. Three months after the final inoculation, rabbits were euthanized and sections of thoracic aortas were blindly evaluated microscopically for maximal intimal thickness (MIT), percentage of luminal circumference involved (PLCI), and plaque area index (PAI) of atherosclerosis. Vascular chlamydial antigen was assessed by direct immunofluorescence. MIT differed among treatment groups (P=.009), showing an increase in infected rabbits (0.55 mm; SE=0.15 mm) compared with uninfected controls (0.16 mm; SE=0.06 mm) and with infected rabbits receiving antibiotics (0.20 mm; SE=0.03 mm) (both P<.025), whereas MIT in infected/treated versus control rabbits did not differ. PLCI also tended to differ (P<.1) and PAI differed significantly (P<.01) among groups with a similar pattern. Chlamydial antigen was detected in 2 untreated, 3 treated, and 0 control animals.

Conclusions—Intranasal C pneumoniae infection accelerates intimal thickening in rabbits given a modestly cholesterol-enhanced diet. In addition, weekly treatment with azithromycin after infectious exposure prevents accelerated intimal thickening. These findings strengthen the etiologic link between C pneumoniae and atherosclerosis and should stimulate additional animal and human studies, including clinical antibiotic trials. (Circulation. 1998;97:633-636.)

Key Words: atherosclerosis • azithromycin • Chlamydia pneumoniae

Atherosclerotic cardiovascular disease is a major health problem, causing nearly half of all deaths in the United States. Several important risk factors for atherosclerosis have been discovered, but much of the risk remains unexplained. Recently, infectious agents have been proposed as a possible additional coronary risk factor. Chlamydia pneumoniae is a newly discovered third species of chlamydia shown to cause pneumonia, bronchitis, pharyngitis, and sinusitis. C pneumoniae also has been associated with coronary heart disease and myocardial infarction in serological studies. More specifically, C pneumoniae antigen and elementary bodies have been found in atheromas from coronary arteries, carotid arteries, and aorta. However, these findings do not establish a causal role. Animal models would be useful in determining causality and assessing the role of antibiotic therapy. C pneumoniae causes pneumonitis in the rabbit, and the cholesterol-fed rabbit is an established model for accelerated atherosclerosis. Thus, the rabbit may be a suitable model to study a pathogenetic role of C pneumoniae in atherosclerosis. Fong et al recently reported on a small study of rabbits nasally infected with C pneumoniae. Two of 11 animals demonstrated early and intermediate histological lesions of atherosclerosis. We hypothesized that repeat infections and the addition of a small supplement of dietary cholesterol would yield more consistent and accelerated development of atherosclerotic lesions and that antibiotic therapy might prevent this process.

Methods

The objectives of the present study were (1) to determine whether repeated intranasal C pneumoniae infection of rabbits fed with chow supplemented with a small amount (0.25%) of cholesterol would result in significant acceleration of atherosclerosis compared with saline inoculation and (2) to assess the efficacy of azithromycin, an antibiotic known to be effective against C pneumoniae, in preventing accelerated development of atherosclerosis.

C pneumoniae Strain and Inoculum

The TWAR American Type Culture Collection strain VR 13103 was used. We harvested viable organisms from infected cultures of HeLa 229 cells by disrupting infected cells with glass beads and sonification. Organisms were partially purified by centrifugation, quantitated, and resuspended in sucrose phosphate glutamic acid with 10% dimethyl...
Experimental Animals and Study Design
Thirty female New Zealand White rabbits (2 to 4 months old, pathogen free) were used. Rabbits were fed standard rabbit chow fortified with 0.25% cholesterol without antibiotics. Animal care and processing were performed under strict adherence to the Institutional Animal Care and Use Committee guidelines. Twenty rabbits were included in the infection arm of the study. Each was inoculated with 1 mL (1 to 5 x 10^4 inclusion-forming units) of C pneumoniae suspension via the nasal turbinates with a plastic catheter under light anesthesia using tiritated intramuscular doses of ketamine. Three separate inoculations were performed at ~3-week intervals (average, 20 ± 1 [SE] days). Three days after final inoculation, 10 rabbits were randomized to a 7-week course of azithromycin. For the first week, a daily intramuscular injection of 30 mg/kg aqueous azithromycin (Pfizer Corp) was given. For the remaining 6 weeks, twice-weekly intramuscular injections of 30 mg/kg azithromycin were given.

Similarly, 10 control rabbits were intranasa lly inoculated three times at 2- to 3-week intervals with 1 mL of normal saline. Thereafter, 5 of the controls were randomized to the same 7-week course of azithromycin.

Three months after final intranasal inoculation (at 132 [SE, 6] days of study), all rabbits were euthanized. The aortas were removed, refrigerated, and sent for pathological evaluation.

Pathological Investigations
Aortic specimens were grossly inspected. Representative cross sections of thoracic and abdominal aortas were removed from each sample. Adjacent sections were submitted for either routine histological evaluation or frozen section staining for direct immunofluorescence. Histological specimens were fixed in 10% buffered formalin, paraffin embedded, and stained with hematoxylin and eosin. The histological sections were evaluated by an experienced pathologist blinded to infection or treatment group. Quantitative evaluation was performed with the use of an Olympus BH-2 microscope equipped with an eyepiece micrometer. The degree of intimal atheromatous involvement was determined by use of three prespecified measures: (1) maximal intimal thickness (MIT), defined as the maximal measurement from the luminal surface to the internal elastic lamina of the vessel wall; (2) percentage of luminal circumference involved (PLCI) with atheroma (this measurement was determined by visual pathological estimate); and (3) plaque area index (PAI). This was defined as the product of MIT and PLCI.

Immunofluorescence
Specimens for immunofluorescence were frozen in optimal cutting temperature medium, cut at 4 μm onto glass slides, and air dried. After 30 minutes, direct immunofluorescence was performed with a prediluted monoclonal antibody (Baxter Scientific). This mouse monoclonal antibody is directed at a 3000-D lipoprotein common to all Chlamydia species (ie, trachomatis, psittaci, and pneumoniae). The antibody has been directly conjugated with fluorescein isothiocyanate.

Results
Twenty-nine rabbits survived and could be evaluated, and 1 (in the infection/no treatment group) died under anesthesia. Fig 1 shows the results of intimal thickening measurements by infection/treatment group. Qualitatively, the lesions were uniformly characteristic of atheromas, with varying proportions of foamy cells, spindle (smooth muscle) cells, and extracellular matrix. The degree of MIT varied among the three treatment groups (P<.009 by ANOVA): MIT was increased in infected rabbits (0.55 mm [SE, 0.15 mm]) compared with uninfected controls (0.16 mm [SE, 0.06 mm]) and with infected rabbits receiving antibiotics (0.20 mm [SE, 0.03 mm]) (both P<.025 by Student-Newman-Keuls test), whereas MIT in treated versus control rabbits did not differ. Response to infection varied among individual animals, with 4 of 10 showing prominent atherogenesis, indicating variability in success of infection or host response. PLCI tended to differ (P=.1) and PAI significantly differed (P=.01) among the three treatment groups: PLCI averaged 50% (SE, 12%) in infected/untreated animals versus 22% (SE, 8%) in controls and 32% (SE, 5%) in infected/treated animals. PAI averaged 40% (SE, 15%) in infected/untreated animals versus 5.0% (SE, 5%) in infected/treated animals (both P<.05 versus infected/untreated animals). There was no difference between controls given antibiotics versus those given no antibiotics in these indexes (P=.43) (Fig 1).
Chlamydial antigen was detected in 2 of 9 infected/un-treated, 3 of 10 infected/treated, and 0 of 10 uninfected animals (differences not significant). Although not statistically significant, rabbits positive for chlamydial antigen tended to show an increased MIT, regardless of treatment group (MIT = 0.54 mm, antigen positive; MIT = 0.30 mm, antigen negative; \( P = .2 \)). No association between age or weight of the rabbits and MIT was found.

Discussion

Study Summary

This study confirms and quantifies the capability of intranasal infection with \( C \ pneumoniae \) to accelerate atherosclerosis in a rabbit model. Additionally, it demonstrates the ability of azithromycin to prevent this accelerated process. These findings are best explained by assigning a causative role to \( C \ pneumoniae \) in the atherosclerotic process and a preventive or therapeutic role to azithromycin. The degree of atherosclerosis acceleration varied among individual animals, suggesting a variability in the success of establishing persistent infection or in host response to infection.

Vascular chlamydial antigen was not a useful quantitative marker of atheromatous effect in our model; it occurred in a small proportion of both treated and untreated animals and was not found in uninfected controls. Thus, infection-related atherosclerosis may occur in the absence of detectable local vascular antigen, and antibiotic therapy may not immediately eliminate chlamydial antigen.

Study Strengths and Limitations

This study was larger and more successful than a previous investigation\(^1\) in demonstrating the potential of chlamydial infection to accelerate atherosclerosis in a rabbit model. Additionally, it demonstrates the ability of azithromycin to prevent this accelerated process. These findings are best explained by assigning a causative role to \( C \ pneumoniae \) in the atherosclerotic process and a preventive or therapeutic role to azithromycin. The degree of atherosclerosis acceleration varied among individual animals, suggesting a variability in the success of establishing persistent infection or in host response to infection.

Vascular chlamydial antigen was not a useful quantitative marker of atheromatous effect in our model; it occurred in a small proportion of both treated and untreated animals and was not found in uninfected controls. Thus, infection-related atherosclerosis may occur in the absence of detectable local vascular antigen, and antibiotic therapy may not immediately eliminate chlamydial antigen.

Chlamydial antigen was detected in 2 of 9 infected/un-treated, 3 of 10 infected/treated, and 0 of 10 uninfected animals (differences not significant). Although not statistically significant, rabbits positive for chlamydial antigen tended to show an increased MIT, regardless of treatment group (MIT = 0.54 mm, antigen positive; MIT = 0.30 mm, antigen negative; \( P = .2 \)). No association between age or weight of the rabbits and MIT was found.

The number of animals was adequate for hypothesis testing, but additional observations will be welcome. The cellular and molecular mechanisms by which \( C \ pneumoniae \) accelerates atherosclerosis were not defined. Also, our data are too limited to exclude a small antiatheromatous effect of azithromycin apart from its antichlamydial actions. Whether \( C \ pneumoniae \) can cause atherosclerosis in the absence of cholesterol feeding was not addressed. The optimal dose and duration of antibiotic therapy are unknown, and further dose-ranging studies would be useful. However, the azithromycin regimen was selected to achieve dose concentrations clinically effective against chlamydiae and for a duration believed to suppress or eliminate chronic, persistent, and acute infection. Finally, it must be remembered that the rabbit model of atherosclerosis is not identical to that of human disease, and any extrapolations must be made with caution and confirmed by clinical studies.

Acknowledgment

This work was supported in part by a grant from the Deseret Foundation, LDS Hospital, Salt Lake City, Utah.

References

Infection With *Chlamydia pneumoniae* Accelerates the Development of Atherosclerosis and Treatment With Azithromycin Prevents It in a Rabbit Model

Joseph B. Muhlestein, Jeffrey L. Anderson, Elizabeth H. Hammond, Liping Zhao, Sanjeev Trehan, Eric P. Schwobe and John F. Carlquist

*Circulation*. 1998;97:633-636
doi: 10.1161/01.CIR.97.7.633

*Circulation* is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 1998 American Heart Association, Inc. All rights reserved.
Print ISSN: 0009-7322. Online ISSN: 1524-4539

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://circ.ahajournals.org/content/97/7/633

Permissions: Requests for permissions to reproduce figures, tables, or portions of articles originally published in *Circulation* can be obtained via RightsLink, a service of the Copyright Clearance Center, not the Editorial Office. Once the online version of the published article for which permission is being requested is located, click Request Permissions in the middle column of the Web page under Services. Further information about this process is available in the Permissions and Rights Question and Answer document.

Reprints: Information about reprints can be found online at:
http://www.lww.com/reprints

Subscriptions: Information about subscribing to *Circulation* is online at:
http://circ.ahajournals.org/subscriptions/