Stronger Relationship Between Particulate Matter (PM) and Premature Death

March 23, 2006

Air Resources Board
California Environmental Protection Agency

Thank you Ms. Witherspoon and good morning Dr. Sawyer and members of the Board. Today's health update will discuss the results of an important new study on particulate matter and its relationship to premature death. What makes this study especially relevant is that investigators studied residents of the Los Angeles basin and found a stronger effect of particulate matter on premature death. Before discussing the study, I'd like to briefly summarize how previous results are being used to support ARB's programs, including standards setting and diesel PM control regulations.

Overview

- Health Effects and confirmatory evidence
- Air quality standards and regulations are increasingly reliant on these study results
- Key studies of mortality effects (premature death)
- A new California-based study (Jerrett et al.) indicates we are underestimating mortality
- Implications for ARB Programs

An overview of my presentation begins with the scientific confirmatory evidence demonstrating that a reduction in particulate matter can be associated with a reduction in premature death.

Then I will discuss how the results of these health studies support our programs, including air quality standards and regulations.

I will review some of the key studies that provide evidence of PM effects on premature death.

And I will end by presenting the results of the new California-based study by Professor Michael Jerrett and colleagues that indicates we may be underestimating PM's impact on premature death and discuss the implications these new findings may have for our health impacts assessments.

What We've Learned to Date

- ~9,000 Californians die prematurely, in 2000, due to particulate matter and ozone exposure above State ambient air quality standards
- Exposures to air pollution can shorten life by about 14 years for people who die prematurely
- Value of preventing premature death is $7.9 million (2005 dollars) by U.S. EPA
- Californian's have a disproportionate share of PM exposure

Let me first summarize what we've learned to date regarding the health effects of air pollution exposure. To date substantial scientific evidence supports the association between PM and ozone exposure to premature death. Based on the results of health studies, staff has estimated that approximately 9,000 premature deaths per year are related to PM and ozone exposures above our state standards for PM and ozone.

We have established that for people who die prematurely, their life expectancy is shortened by about 14 years on average.

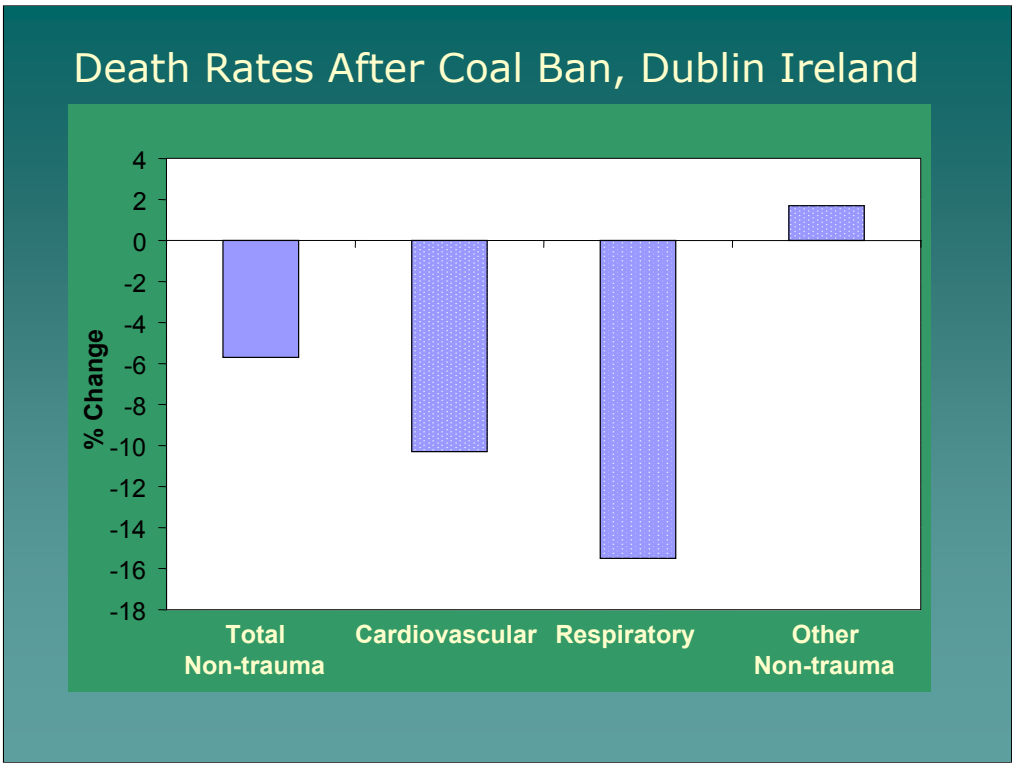
In addition, U.S. EPA has estimated a value of life at $7.9 million in the year 2005. EPA based its estimate on 26 peer-reviewed studies that measure an individual's willingness to pay to obtain a small decrease in the annual risk of mortality.

Californian's have a disproportionate share of the national exposure to particulate pollution. Californian's residents receive more than 60% of the population-weighted exposure to PM2.5 values above the National annual standard of 15 ug/m3 and we are virtually the only state to experience violations of the current 24-hour-average PM2.5 National standard of 65 ug/m3.

Scientific Confirmatory Evidence

- Observed health improvements following significant emission reductions
  - Coal ban in Dublin, Ireland
  - Sulfur reduction in Hong Kong
  - Steel mill closure in Utah Valley
  - Children's Health Study

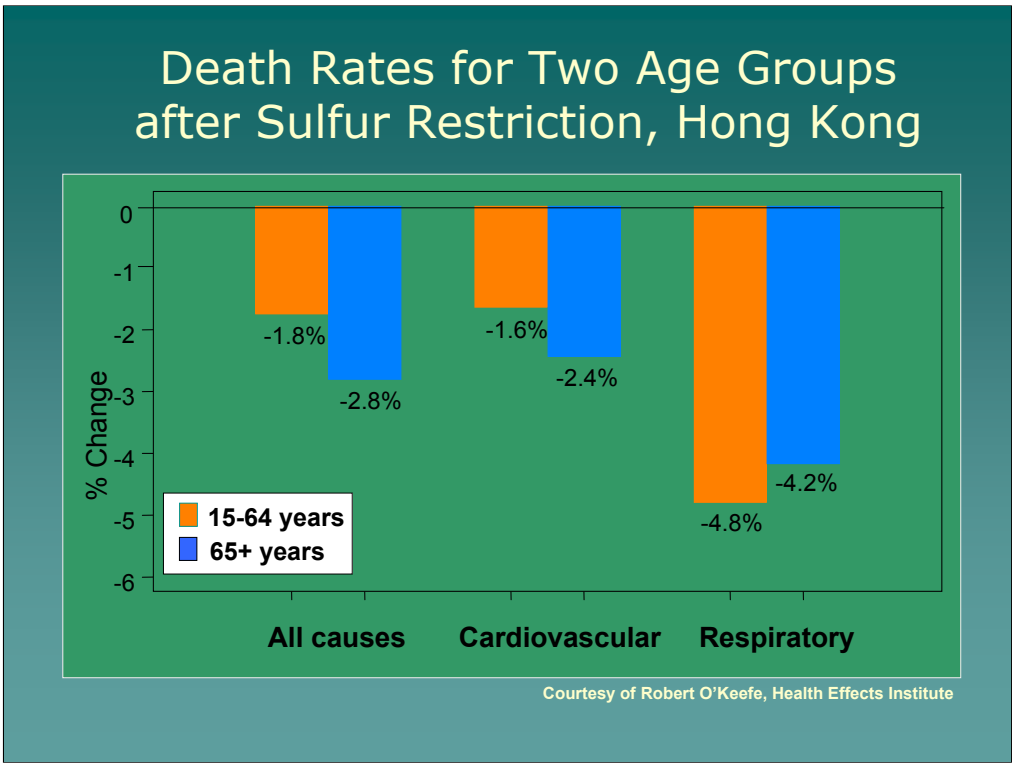
The next slides provide confirmatory evidence which demonstrate that improving air quality has a positive effect in reducing adverse health effects, including premature death. I'd like to briefly highlight four studies indicated on this slide, generally referred to as "intervention" studies.



In 1990, the Irish government banned the marketing, sales and distribution of soft coal within the city of Dublin. The investigators examined the effect of this intervention on the association between ambient air quality and death rates.

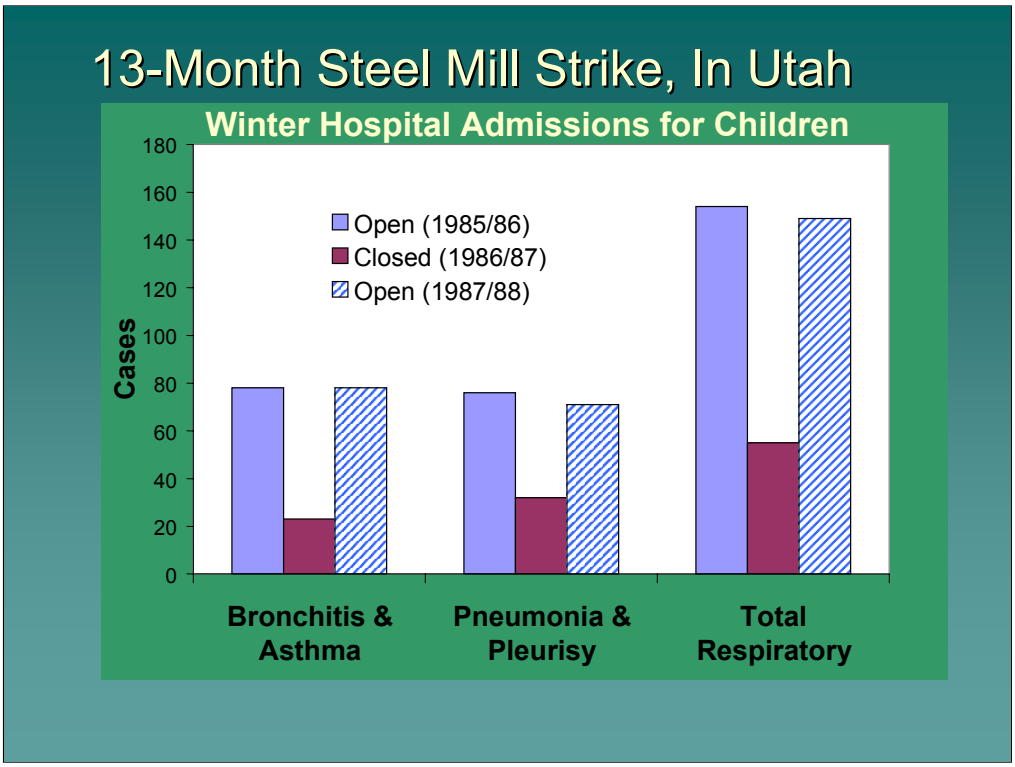
The researchers found that the ban of coal sales resulted in a 70 percent reduction in PM from black smoke and a 30 percent from sulfur dioxide in the following 5 years.

The result was researchers found a 6 percent decrease in non-trauma deaths. This decrease in total non-trauma deaths was primarily driven by an estimated 10% and 16% decrease in the rates of death from heart and lung diseases, respectively. These findings suggest that control of particulate air pollution can lead to immediate and significant reductions in death rates.



In 1990, Hong Kong lowered the sulfur content of fuel oil. The regulation resulted in an average 53% reductions in sulfur dioxide concentrations from fuel combustion.

As shown in this slide, the annual average mortality rates for all causes, cardiovascular and respiratory diseases declined substantially after the regulation.



In the United States we have the example of the health improvements following the temporary closure of a steel mill in Utah Valley, Utah. During the period of August 1986 to Sept 1987, a steel mill, which was the primary source of particulate pollution, was closed due to a workers' strike.

This graph shows the number of children less than 18 years of age admitted to the regional hospitals for respiratory causes during the winter months between 1985 and 1988. The investigators found that during the 1986/87 winter season, when the mill was closed, hospital admissions for children were approximately 3 times lower than when it was open -- as indicated by the dark red bars. Statistical analyses showed that this decrease was associated with the decrease in PM10 levels.

Relocation and Lung Function, Children's Health Study, California

- Children's Health Study followed relocated children from the larger study
- Decrease in PM10 exposure associated with an increase in lung function growth rate
- Increase in PM10 exposure associated with a decrease in lung function growth rate

Closer to home the Children's Health Study investigators studied the health effects of relocating to areas of differing levels of air pollution.

They followed 110 children from the larger Children's Health Study who moved to 6 western states at least one year before follow-up into to areas of higher or lower pollution.

They found that children moving to areas with lower PM10 levels experienced an increase in lung function growth rates. Conversely, moving to areas of higher PM10 resulted in a decrease in lung function growth rate.

Support of ARB's Programs

- Set State particulate and ozone standards below the level of adverse health impacts and urged U.S. EPA to do the same
- Health benefits of State standard attainment
- Health benefits of adopting diesel control measures to cut PM exposure 85% by 2020
- Added "lives saved" to cost-effectiveness calculations

So how does the ARB use the overwhelming scientific evidence from the many health studies. Many of these studies are the basis for the Board's action to establish new State particulate and ozone standards and at levels below those observed to cause adverse health impacts to provide a margin of safety. They also provide the scientific support for our comments to U.S. EPA to follow good science in establishing the national ambient air quality standards.

In addition, staff uses the study results to estimate the health benefits of attaining standards and adopting our diesel PM control measures in order to cut PM exposure by 85% by 2020. The Board has also added "lives saved" to cost-effectiveness calculations.

Cost-Effectiveness

- Compare Health Benefits with Control Costs
- Methods endorsed by NAS, U.S. EPA, WHO
- Diesel PM Regulations
  - $4 to $28 of benefits per $1 of control
- Goods Movement Plan
  - $3 to $8 of benefits per $1 of control

The ARB has also responded to the scientific evidence by applying the studies findings to our cost effectiveness calculations. It is important to know that the ARB uses its cost-effectiveness evaluations to help guide the decisions on the impacts of the control measures.

ARB measures regulatory cost-effectiveness by comparing the anticipated health benefits of reducing air pollution to the anticipated costs of achieving those reductions. These comparisons require both benefits and costs to be quantified and monetized, that is, converted to dollars.

ARB strives to reduce the uncertainty of its estimates by using generally accepted methods and values established by organizations such as the National Academy of Sciences, U.S. EPA and the World Health Organization.

Cost-effectiveness measures are presented in the form of a ratio between the value of the health benefits and anticipated control costs.

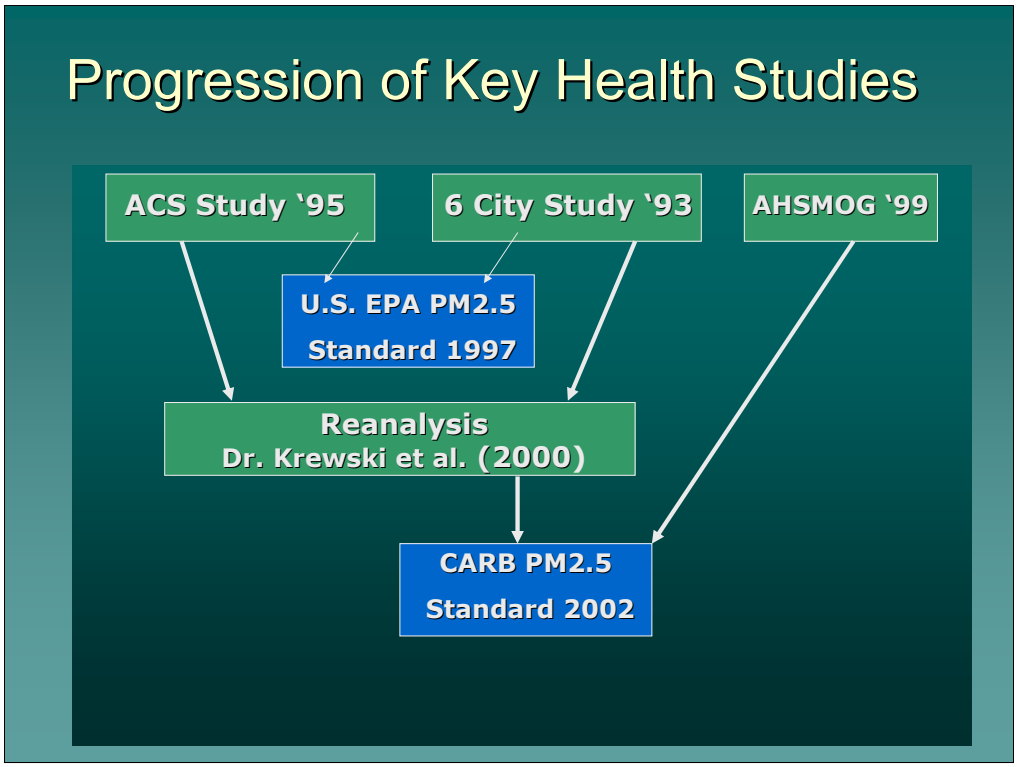
For example, the Diesel PM regulation is estimated by ARB to yield 4 to 28 dollars of health benefits for every dollar spent on control costs.

Likewise, the plan to reduce Goods Movement emissions, released earlier this week will result in 3 to 8 dollars of health benefits for every dollar of control costs.

Where do These Numbers Come From?

Key PM Mortality Studies

Now I'd like to turn my presentation to the key studies that provide the numerical values we use to support our programs.



The potential for particulate air pollution to cause excess deaths and disease, especially after severe air pollution episodes, has been well established since the 1960's. However, in the 1990's, three landmark studies were published that addressed the long-term effects of low level PM exposure on premature death. They were the American Cancer Society study, the Six Cities study, and the Adventist Health Study on the Health Effects of Smog (or AHSMOG).

Of these studies, the first two were key in the U.S. EPA's decision to establish a new annual PM2.5 national standard.

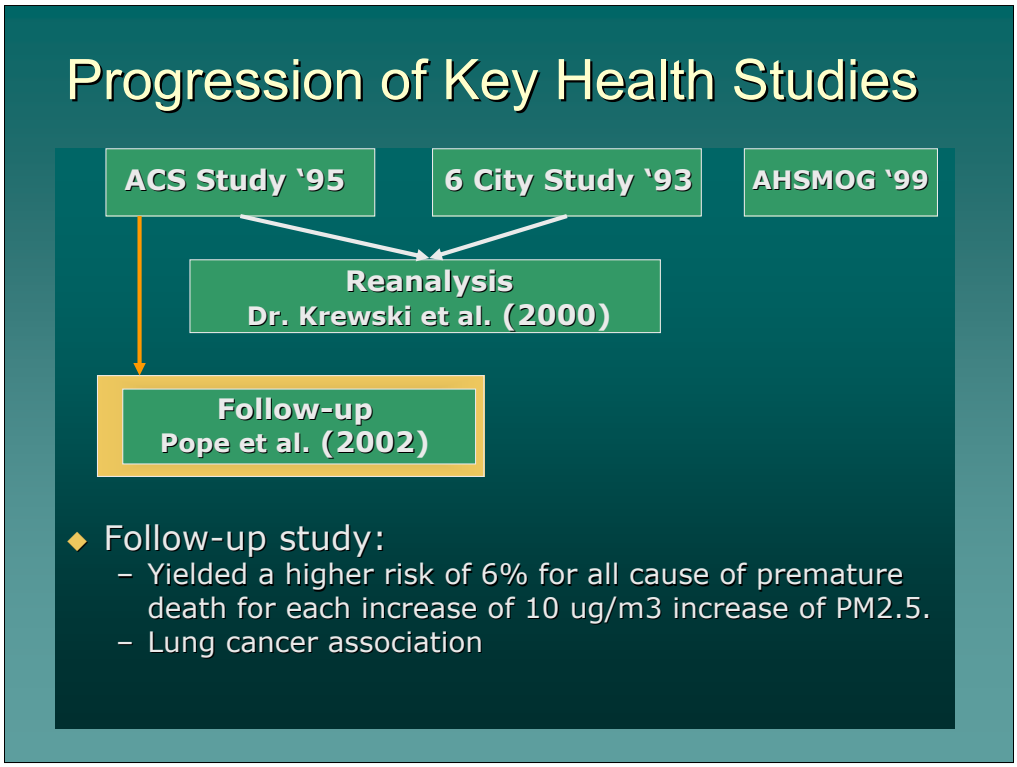
In 1993, Professor Dockery and his colleagues published results from the Six Cities Study. The researchers followed over 8000 adults living in six cities for about 15 years and examined the effect of PM in six cities in the eastern part of the county. They reported a statistically significant increase in premature death due to long-term exposure to PM.

In 1995, Dr. Arden Pope and his colleagues published results from their American Cancer Society study or "ACS" study. Investigators followed a group of over ½ million people in over 50 cities in the United States for 7 years and also reported an association between long-term PM exposure and premature death.

The results from those two studies came under intense scrutiny in 1997 when the U.S. Environmental Protection Agency used them in support of A new National Ambient Air Quality Standard for PM2.5.

As a result, and due to their significance in the standard setting process, an independent reanalysis was performed in 2000 by Dr. Krewski and colleagues which assured the quality of the data set and validated these studies' findings.

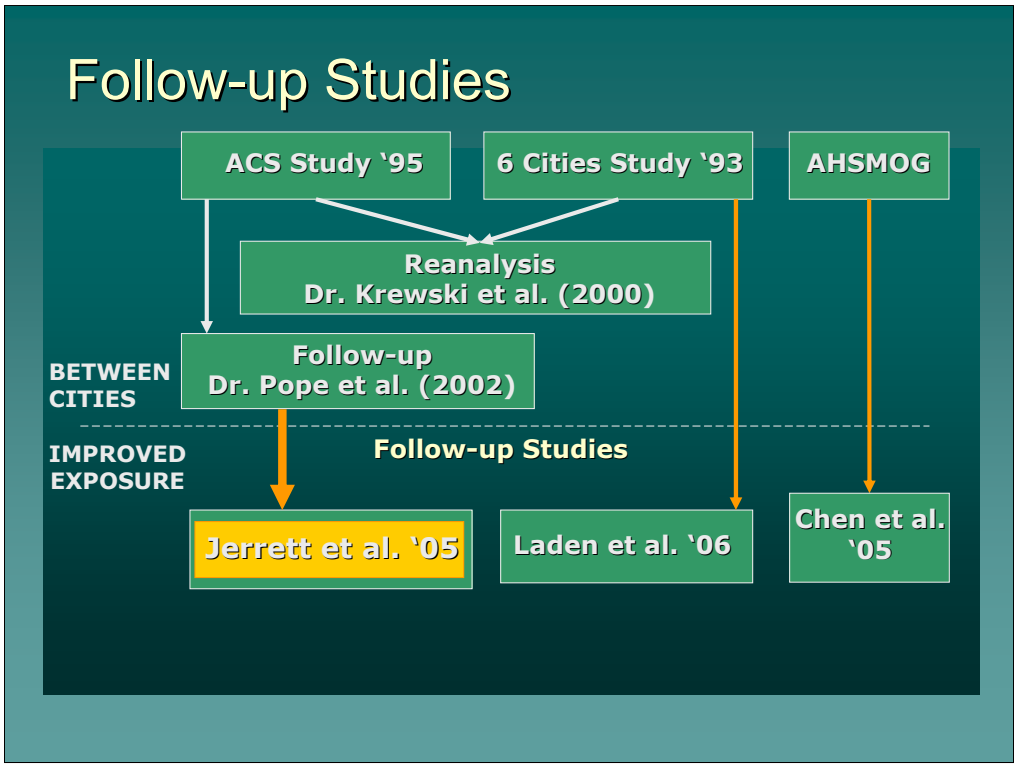
The reanalysis of the Nationwide ACS study and the six city study, along with the results from the AHSMOG study were used by ARB to support the establishment of a State annual PM2.5 standard. The Krewski reanalysis study results were used to quantify the health benefits that would accrue if California attained the new State annual standard.



In addition, these studies also triggered extensive efforts of follow-up studies.

In 2002, Pope and colleagues published their follow-up study to the ACS. This follow-up study doubled the follow-up time to more than 16 years, which tripled the number of deaths in the group, as well as applied recent advances in statistical analysis. These improvements from the original ACS study yielded an estimated 6% increased risk of all cause premature death for each 10 ug/m3 increase of PM2.5 exposure. They also reported a significant increase in death from lung cancer, which had not been reported in these studies before.

This follow-up study was published while CARB was finalizing its PM2.5 standard and was therefore too late to be included in our peer-review. But was submitted in public comments and has since become the primary study for use in health impact analyses such as this week's goods movement emissions reduction plan.



The last 6 months has seen a plethora of follow-up studies to the original long-term effects PM studies. In December 2005, a follow-up to the AHSMOG study was published, Chen et al., and we presented the results at the December health update.

Just last week, a follow-up to the Six Cities study was published, by Laden et al.

And in November 2005, Professor Jerrett published his paper which followed-up on the national ACS study but looks only at Los Angeles residents.

And that is the focus of today's health update.

Spatial Analysis of Air Pollution and Mortality in Los Angeles

Jerrett et al. (2005)

Professor Jerrett conducted the study in collaboration with Dr. Pope and Dr. Burnett of the original 1995 ACS study. Because the new study by Jerrett used a subset of the 2002 follow-up ACS study cohort, it's important to compare the methods and results from the two studies in our discussion. The next few slides will do just that.

Study Population

SAME

- American Cancer Society (ACS) Cohort
- 1982 at recruitment -both males and females were 30 or older
- Comprehensive questionnaire
  - Diet, smoking history, occupational, education, alcohol use, weight, etc.

DIFFERENT

National	versus	Los Angeles
1982–1998		1982–2000
51 cities		LA region only
500,000	ACS Cohort Size	22,905

The population used in these two studies came from the American Cancer Society (ACS) cohort.

The ACS cohort was designed to investigate the relation between lifestyle factors, exposures and risk of cancer, mortality, and survival. When the investigators begun recruiting subjects in 1982 for this cohort, participants were age 30 or older with at least one other person in the household age 45 or older. The participants of the ACS cohort were given a comprehensive questionnaire that included diet, smoking history, occupational, education, alcohol use, weight, etc – factors that are known to confound with the effect of PM on premature death. New questionnaires were sent to surviving cohort members every other year to update exposure information and to ascertain new occurrences of cancer.

The difference between the two studies is that Pope conducted it at the national scale, while Jerrett performed a detailed analysis using data in the Los Angeles region. The National study uses ACS subjects from 1982 to 1998, whereas the LA study included a subjects from 1982 to 2000. The total number of subjects included in the national study was approximately ½ a million whereas the LA study included about 23,000 of these, and reported 5,800 deaths.

In summary the Los Angeles study by Jerrett was much smaller in size than the National ACS study, representing only approximately 6% of the total National ACS study.

Methods

SAME

- PM2.5 only
- 44 confounders

DIFFERENT

- LA study
  - Additional confounding factors such as income, education and crime rate
- Exposure
  - National: average PM2.5 for a city assigned same value to all participants in city
  - LA: PM2.5 data from 23 sites for 2000 then modeled and assigned to zip-codes

Both studies compared the effects from PM2.5 exposure to the cohort and also added 44 potential confounders to the analysis. Potential confounders need to be controlled for in order to isolate a definitive effect from PM2.5. The 44 confounders came from the routine questionnaires sent to the participants.

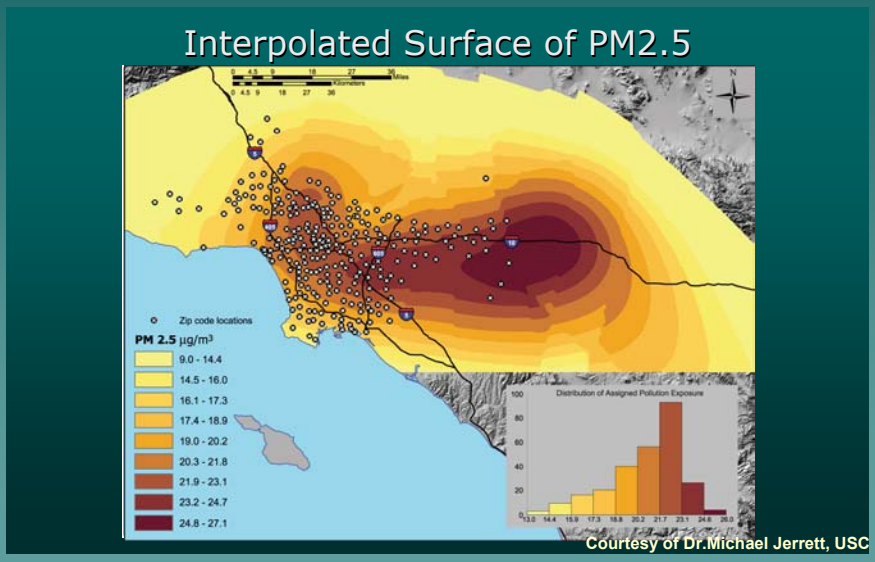
The difference between these studies is that the Los Angeles ACS study added additional social factors in addition to the 44 confounding factors used in the National ACS study. The additional social confounding factors where specific to the Los Angeles cohort such as income, crime rate and education.

The biggest difference was their exposure calculation. The investigators from the National study averaged the PM2.5 concentrations for each city and assigned this exposure level to everyone in the city.

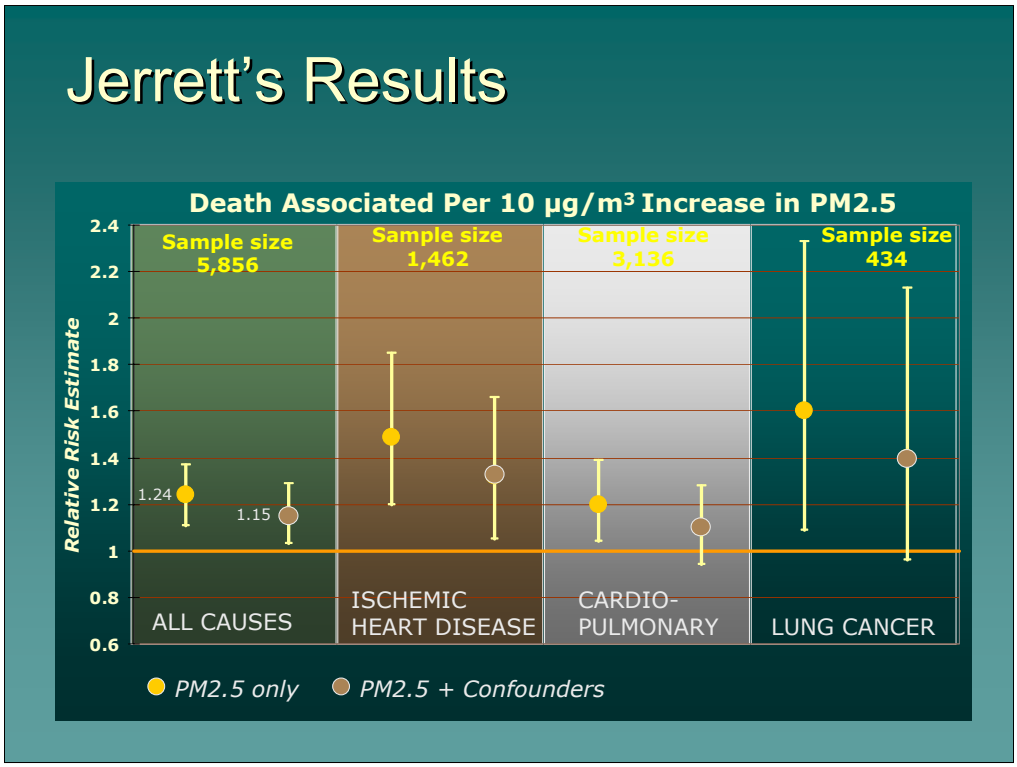
The investigators from the LA study used year 2000 data from 23 sites and modeled the values and then assigned the same exposure level to everyone living within a zip code. Each of the 267 zip codes were assigned different PM2.5 exposure values.

In summary, the LA follow up study had better exposure assessment methodology and considered additional confounders that are more pertinent to the Los Angeles region.

Air Quality Data in Jerrett Study



This map consists of the interpolated surface used by the Los Angeles ACS study. The yellow color represents lower concentrations of PM2.5. The more urbanized area of Los Angeles have PM2.5 higher concentrations represented by the brown colors. The circles are the center of the zip code. The graph to the lower right shows the pollutant level attributed to the ACS population. Note, most of the ACS cohorts is located in the Los Angeles county where the concentrations assigned to the majority were high but not the highest.



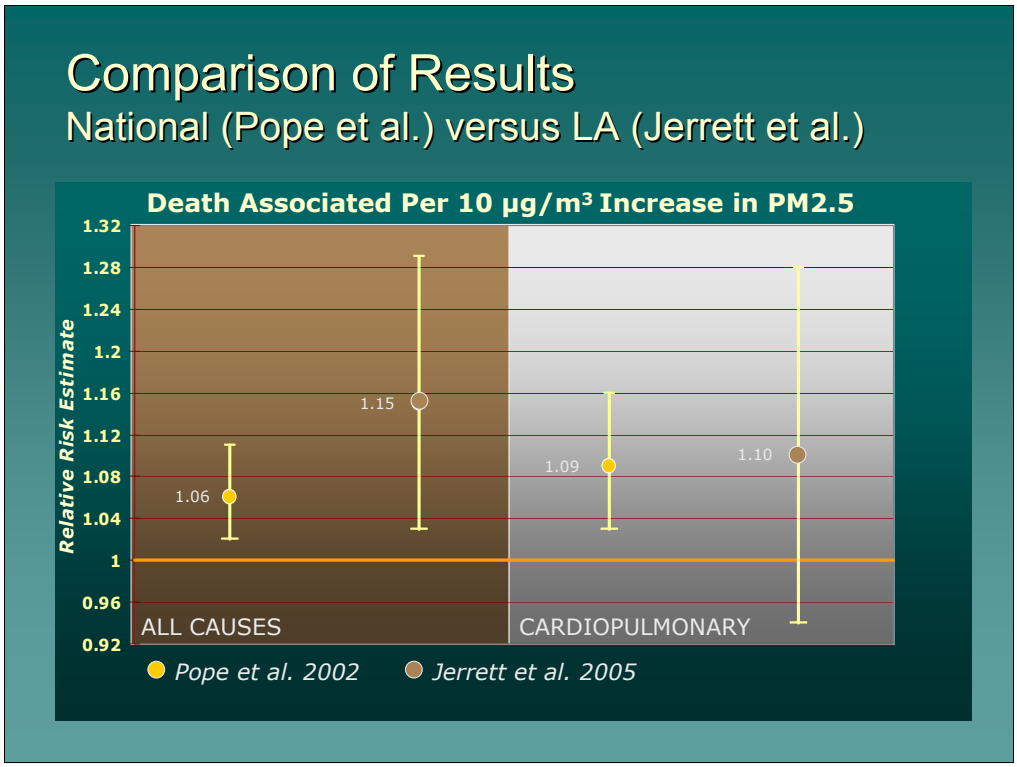
I will now discuss the results for death due to all causes for the Los Angeles ACS study.

When the investigators did not control for any confounders, they observed a 24% relative risk associated to a 10 ug/m3 increase in PM2.5. These results are shown in YELLOW CIRCLES in this graph. Since there are other factors besides PM2.5 that may cause premature death including weight, smoking, diet, etc., they must be included to ascertain the "true" effect from PM2.5 on premature death. When the investigators added these confounding factors to their model, the pollution effects remained significant at a 15% increase in relative risk per 10 ug/m3 increase in PM. They are shown in BROWN CIRCLES in this graph.

This 15% effect is slightly lower than the publicized 17% because it includes all social factors in addition to the 44 original ACS confounders therefore lowering the relative risk from 17% to 15%, but increasing the confidence.

In addition, the investigators showed a significant association between PM2.5 and death from ischemic heart disease and not as significant for cardiopulmonary and lung cancer. The relative risk for these are between 10% to 43% when all 44 ACS confounders plus all social factors are added.

The statistical significance of these results are not as strong as for all causes the number of deaths due to specific causes is smaller than from all causes. It is expected that as the number of data points gets smaller, the error bounds would increase – indicated by the wider confidence intervals -- giving the researchers less confidence in the results. However, other studies have corroborated the PM2.5 effects with these same health outcomes.



When we compare the results of death due to all cause between the National study by Pope et al. 2002 and the Los Angeles study by Jerrett et al. we observe that the relative risk associated with a 10 ug/m3 increase in PM2.5 is approximately 2 and ½ times higher for the Los Angeles study.

While the central estimate – indicated by the brown circle in this chart – appear much larger for the Jerrett study, one must keep in mind the lower and upper bounds of the two results. Since they overlap, the results from the two studies should be interpreted as statistically NOT different.

The national ACS study is a between city study versus the Los Angels ACS study is a with-in city study. There is a consensus amongst leading researchers that new studies such as the Jerrett et al. with better exposure measurements are finding higher effects from PM2.5.

When we compare the PM2.5 effects on cardiopulmonary health from the Los Angeles study the result is higher than the National, but the confidence bounds are much greater because of a smaller sample size. However, both studies find a similar central estimate of relative risk for cardiopulmonary death between 9 and a 10% per 10 ug/m3 increase in PM2.5.

Summary of Jerrett's Results

- Within-city exposure gradients show PM2.5 effects on premature death 2.5 x higher than across-city studies, but uncertainty range is wider
- Strongest effects from PM2.5 with ischemic heart disease and all-cause deaths

In summary Jerrett's results demonstrate that the within-city gradients in exposure show PM2.5 effects of premature death 2 and ½ times greater than across-city studies. However, the uncertainty range is wider than that in the National ACS study since a much smaller number of participants were considered.

The Los Angeles ACS study saw the strongest effect from PM2.5 on death from ischemic heart disease.

Strengths of Jerrett et al. Follow-up Study

- Studied real people in California environment
- More accurate PM exposure measurements
- More typical mixtures of air pollution, including freeway emissions
- Captured potentially vulnerable groups

The strength of this study is that it provides a way to examine exposure-response relationships under real-world conditions within the Los Angeles region.

In addition, the investigators used more accurate PM exposure measurements by attributing to the ACS cohort with-in city pollution levels.

Further, this study captured a more typical mixture of air pollution, including freeway emissions that tend to dominate California's urban ambient air pollution.

Finally, this study may have potentially captured a vulnerable groups such as the very old and those more susceptible to hart disease.

Weaknesses of Jerrett's work

- Less statistically robust
- Dividing analyses (cities, causes of death, sub-populations) increases range of uncertainty
- Not all potential confounders measured (stress, other pollutants)
- May not be representative of other CA regions

The drawbacks of this study are the reduced number of participants which result in larger confidence bounds behind all the results and therefore less statistically robust.

By dividing the analyses into specific causes of death and the geographic area into zip codes, the sample size decreased substantially and therefore, the range of uncertainty became larger. In some cases, the results became insignificant.

Further, there may be more potential confounders that were not measured such as stress or other pollutants. This study looked at ozone and saw no confounding – as was done by Pope for the larger study. However, Jerrett et al was unable to examine the confounding effects of other speciated pollutants.

Lastly, although this is a Los Angeles study, questions remain on how representative the results are for other CA regions.

Where the Science is Going?

- Supports general conclusion on association of PM exposure and premature death
- Strengthens association with cardiovascular impacts of PM
- Improves on exposure characterization
- Provokes issue of underestimation

However, overall, the study does provide strong supporting evidence for the adverse health effects of PM.

The study furthers our understanding of the health effects of PM exposure, especially the strong cardiovascular effects seen in this and other studies.

The study's better exposure characterization may be limiting the exposure misclassification that is certainly a part of other long-term studies that rely on central city estimates for whole metropolitan areas exposures.

It does raise the issue of whether previous studies have underestimated the health impacts of long-term PM exposure on death and disease.

Next Steps

- Replicate in Other Large Cities
- Pooling
  - Blend strengths of LA study with greater statistical certainty of national study
  - Review results of new studies to be published later this year
  - Consistent methodologies with other environmental agencies
  - Peer review methodology

In summary, the more focused study by Jerrett in the Los Angeles area is useful in furthering our understanding of PM pollution and premature death for California. Due to its significance for California further studies like this one in other large cities would validate these studies' findings.

In the next several months, staff plans to seek advice from national experts on the subject on how to best blend the strengths of the Los Angeles study with greater certainty offered by the larger national ACS study.

With new PM mortality studies coming out later this year, timing will be right for us to consider revising our health estimates.

We will make sure that our approach for evaluating factors on PM mortality as well as other health effects is consistent with the methodology used by other environmental agencies, including U.S. EPA.

We expect to have that methodology peer-reviewed.

Policy Implications

- Air Pollution Causes Premature Death
  - Greater share of total CA deaths than estimated to date, but range would widen
  - Will increase public demand for progress
- Particulate Matter Standards
  - Stronger support for standard attainment
  - Attainment provides larger benefits
  - Current CA standard protective enough

Concluding remarks, I have presented to you evidence that air pollution from PM2.5 causes premature deaths, and how using the new studies may mean that more deaths could be attributed to air pollution, but the range would be wider. The results of the new study provides stronger evidence to increase public demand for progress in attaining the ambient air quality standards, which have been set to protect public health. The new study provides the Board with important support for attaining the standards since it confirms that attaining the PM2.5 standard will lead to improved health benefits. Our current California standards are protective and this study does not challenge this conclusion.

Policy Implications, continued

- Diesel Regulations
  - Health benefits greater than previously estimated
  - More cost-effective than previously thought
- Communications / Public Education
  - Need to get revision right and explain basis
  - Message is not *"more people are dying"* but rather *"air pollution is the hidden cause of deaths that were previously attributed to other causes"*

ARB's regulations to control diesel PM emissions are on track to achieving the 85% reduction goal in year 2020. The new evidence may suggest that our rules and regulations may be more cost-effective than previously estimated.

However, until we can confer with leading experts on how to best incorporate the information, it is best to inform the public that our programs are working in reducing the public burden from air pollution, NOT that more people are dying, but rather "air pollution may be the hidden cause of deaths that were previously attributed to other causes".

Stronger Relationship Between Particulate Matter (PM) and Premature Death

March 23, 2006

Air Resources Board

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This concludes my presentation. We will be happy to answer any questions.

Thank you very much.