REVIEW OF BODY COMPOSITION RESEARCH AT THE UNIVERSITY OF WISCONSIN

1960-1970

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Introduction

This paper reviews a small portion of a field which involves a currently popular concept--multi-disciplinary research. Measurement of body composition in vivo has several aspects but the one that has received the most attention and which will be the primary concern of this report involves the measurement of bone mineral in vivo. This research is of interest to many different medical specialties especially internal medicine, orthopedic surgery, radiology, geriatrics, etc. and on the physical side it involves physicists, chemists and engineers as well as computer-oriented individuals. Much of the work that has been performed in our laboratories in the field of body composition is available either in the scientific literature or as USAEC or NASA progress reports (See Appendices I & II). The principal purpose of this report is to "tie it all together".

It is a truism that all scientific work is based on earlier work by other investigators. It is not always possible to trace that sometimes tortuous path by which the work of one scientist affects the work of a later scientist. I realize that I may occasionally fail to acknowledge earlier work but it is out of ignorance rather than malice. It should also be remembered that the work in this research area at the University of Wisconsin is the composite effort of many individuals. Appendix III lists the various individuals who have been connected with the projects over the years. Many of these names will be familiar because of their appearance on our various progress reports. I owe a debt of gratitude to all of these individuals and to many other scientists both in the United States and abroad who have contributed to my understanding of the field. I owe special thanks to two individuals for the quality and quantity of research performed; these are James A. Sorenson and Richard B. Mazess.

It is possible to do research without financial support but you can't do much! The initial work on this project was started with borrowed equipment and there were no funds available for the first six months of the project. The history of the financial support of this project is contained in Appendix IV. I hereby acknowledge and express my deep appreciation for the funds that have been received from all sources. I am particularly appreciative of the U.S. taxpayer who has carried the greatest financial burden of this research in recent years through funds appropriated to the USAEC and NASA. I hope that the results were worth the investment.

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Historical Background

I am sure that Roentgen, when he discovered x-rays, was aware that the technique gave some measure of the bone mass as indicated by the optical density of the shadow of the bone on an x-ray film. In 1901 Price, a U.S. dentist, was probably the first person to try to quantitate the amount of bone mineral on an x-ray film using a step wedge not too different from those that are in current use (1). Since that time there have been many individuals who have worked on the problem of determining bone mineral in vivo but a successful technique which could be used routinely in the average medical center was not developed despite the great abundance of x-ray equipment. A 1964 bibliography by Garn summarized the literature available on the field up to that date (2). In addition to this bibliography there have been a number of meetings devoted primarily to the problem of bone measurements (3, 4, 5).

As can be observed from my curriculum vitae (Appendix III), I entered the field of medical physics in 1958 when I came to the University of Wisconsin with a joint appointment in the Departments of Radiology and Physics. About July, 1959, in a conversation with Dr. L. W. Paul, chairman of the Radiology Department, I asked him what problems he felt could possibly be solved by a medical physicist working in Diagnostic Radiology. He pointed out that there was a need for a reliable and accurate method of measuring "bone density" in vivo. He explained that if a radiologist compares two films of the same bone on a given patient taken some months or years apart it requires a change of from 30-50% in order for the radiologist to be sure that there has been an actual change. I found this rather hard to believe but I have since become convinced of its general validity. The ability to detect a change should not be confused with the ability to make a diagnosis of osteoporosis, which is a qualitative judgment and can be done with more reliability than the judgment of whether one film shows more or less bone than an earlier film. Even in the diagnosis of osteoporosis, however, the appearance of the bone shadows on the film is greatly affected by the technique and it is rather easy to make a normal spine appear either under- or over-calcified by using higher or lower KvP radiation than would be used for the normal exposure.

I reviewed the x-ray film densitometry technique for measurement of bone mineral and I was disappointed in both its precision and its accuracy. I concluded that the technique, though based on physical principles, was too complex for a straightforward analysis for the following reasons:

- a) The heterogeneous beam from an ordinary x-ray unit has many different energies and the absorption coefficients in bone change drastically over the range of energies in the beam (15-80 KeV).
- b) The large beam usually used for x-ray film produces a large amount of scatter which is difficult to evaluate on the film.
- c) The optical density of the film is non-linear
 - i) with respect to photon energy
 - ii) with respect to quantity of radiation.

In addition to these problems there were some common misunder-

standings associated with the technique which still persist. These are:

- a) Because optical density of the film can be measured with high precision and accuracy some individuals assumed that the bone measurements made from the film would also have similar high accuracy and precision.
- b) Because the technique used an optical density measurement it became common to refer to the results erroneously as a measurement of "bone density". Since the volume of bone was usually not known the technique actually measured bone mineral mass.

This latter confusion is somewhat compounded by the common assumption that patients with osteoporosis have bones whose density is much less than that of normals. Although the bone mass is usually much less, the actual density of the compact bone is perhaps only 20% less than that of normal compact bone.

The improved technique developed in our laboratory, although based on the same physical principles as the film densitometry method (i.e. absorption of radiation by bone mineral), removed to a large extent the sources of error listed above. This was brought about by:

- a) Using an essentially monochromatic radiation source from a radioisotope to eliminate the uncertainty in the absorption coefficients,
- b) Using a narrow beam of radiation (which is moved slowly across a bone) to reduce scattered radiation to a negligible level, and
- c) Using a scintillation crystal detector and related electronics to detect and count each transmitted photon.

Essentially all of these ideas have been applied to various related problems and from a physics standpoint the improved technique is really an application of relatively elementary physical principles.

The availability of monoenergetic sources was severely limited and our original work used Pb-210 which was available from decayed radon seeds. The 46.7 KeV gamma ray worked quite well for the original studies although its strength was extremely small such that a scan which can now be done in 10 seconds required 10 minutes to perform.

Medical Implications

Bone is a rather unusual organ of the body since it is so slow in its dynamic functions compared to the other body organs. Although it had been recognized for many years that demineralization occurs with age, especially in women, this was accepted as a natural condition and it was assumed that it must always be thus. It was and is difficult to obtain information on bone directly since it is not readily accessible for sampling and the indirect measurements such as blood calcium, and urine calcium, do not give direct information on the important parameter of bone mineral mass. Calcium balance studies where the total calcium in the diet and the total calcium excreted is monitored has occasionally been used for a few small studies but since the gain or loss in bone mineral is relatively small compared to the total diet calcium it is difficult to get good quantitative answers from this technique.

The development of a precise and accurate assessment of bone mineral appeared to me to be a significant advance which would have far-reaching implications for the medical profession. I was somewhat disappointed that the improved technique did not receive wider acclaim. I believe I now understand the basic reasons. These are:

- 1) The medical profession quite readily accepts new improvements in conventional instrumentation but the development of a device to measure a parameter which has not previously been measured is not so readily accepted. Since physicians had not previously had information on quantity of bone mineral, they were not aware of the value or importance of such measurements.
- 2) For any technique to become widely accepted it must have reliable readily available commercial equipment. This has only been possible using this technique in the last years.
- 3) The technique must be basically simple and the results presented in a straightforward manner. This has been accomplished by developments in our laboratory within the last two years and a commercial unit on the market now fulfills this requirement.

The usefulness of the technique for research was rapidly recognized and the method has been widely copied. A list of some of the medical centers now using the technique is given in Appendix V. Many of these institutions have contributed improvements to the method.

An important aspect of the improved technique is the fact that various laboratories can compare their results directly. We have recently started a program of sending bone phantoms to the various laboratories for inter-calibration purposes.

Communication in Bone Mineral Research

Communication in any inter-disciplinary field is always a problem since each group tends to attend meetings of its parent science and to publish in the specialty journals of the parent science. The situation in this field is further aggravated by the large number of medical specialties that are interested in bone. In any one year, there are usually several meetings dealing with the subject of bone but the measurement of bone mineral is usually a small aspect of these meetings. The first meeting that dealt specifically with bone mineral measurements was held in 1965 in Washington, D.C. sponsored by NASA (3) and a similar meeting was held in 1968 in Bethesda, Md. sponsored by the National Institute for Arthritis and Metabolic Diseases (4). On April 25, 1969 we held a small meeting on bone mineral measurements at the O'Hare Airport in Chicago. The purpose of the meeting was to exchange information, discuss standardization and inter-calibration, etc (See Appendix VI). We originally expected 20 to 30 participants but word of the meeting spread and we ended up with a total of about 65. The meeting was open to all interested individuals and anybody who wished to present information was welcome to do so.

Because of the success of this meeting it was decided to have a similar meeting again in 1970. After a preliminary inquiry we decided to hold the meeting May 22-23 at a hotel near the Chicago O'Hare Airport. The first day of the meeting was reserved for measurement techniques, standardization, radiation sources, etc. The second day was reserved for papers dealing with results of bone mineral measurements. There were 125 attendees of which seven were from Europe. The meeting was held without requesting funds from any government or private agency and again any individual wishing to present information was given time on the program. In addition, a proceedings was prepared including all papers which were submitted (5). If a speaker did not include his paper the abstract or an extended abstract was printed. The proceedings of the conference also included the major portion of the discussion. The proceedings were printed by photo-offset techniques directly from the submitted typescripts thus saving a considerable amount of time in the publication. Since it is a rapidly developing field it is important to make the proceedings available as soon as possible to other scientists who were not able to attend the meeting.

The meeting included exhibits of three commercial bone mineral measuring units (two from the U.S. and one from Sweden) and the scientific session included presentations on the two units manufactured in the United States. The table of contents of the proceedings and attendees of this meeting are included in Appendix VII.

Future Work

Several papers at the meeting just mentioned above were concerned with measurement of body composition by photon absorptiometry and I would expect the interest in this field to grow over the next few years. It seems to be in about the same scientific position bone mineral measurements were in 1963. At the present time there is no satisfactory method for determining the fat to muscle ratio of the body and the technique involving measurements with two different photon energies gives promise to resolve this problem.

Although considerable progress has been made in automation of the bone mineral measurement, much work remains to be done. I am sure we will see more use of on-line computers to calculate the bone mineral. We will also see an emphasis on increased precision of the bone mineral measurement through improved techniques in repositioning the patient or subject. At the present time, repositioning errors appear to limit the precision of the technique to about 1%. Theoretically this can be reduced without an undue radiation exposure or an undue time increase to a precision of 0.1%.

Because many diagnoses of osteoporosis are based on spine measurements there will continue to be developments in the measurement of the bone mineral of the vertebrae extending the work which has already been done (6, 7).

This work on the spine will require the use of at least two photon energies and I am sure we will see further development of multi-photon techniques perhaps using three or four different photon energies. In order to use these effectively it will mean using detectors of higher energy resolution such as lithium drifted silicon detectors. At the present time these detectors are quite expensive when one considers the necessary associated equipment.

Avalanche detectors, which are very efficient at low KeV, appear promising for the development of a less expensive bone mineral measuring device as well as for measurements of skin composition by absorption.

Much of the work in the past has consisted of measurements at a single site or at only a few sites. We have long hoped to do measurements over an extended area of bone using rectilinear scanning but we have been slowed up because of the need of an on-line computer to handle the large volume of data produced. Area scanning will certainly receive greater emphasis.

The application of the techniques to measurement of tissue composition will almost certainly be extended not only for fat to muscle ratios but also other measurements, e.g. the composition of skin.

Perhaps most importantly the technique as it now stands will be applied to many studies including serial studies on the same individuals over a period of years. At the present time much of our data on bone mineral is based on comparisons of different individuals at different ages rather than of the same individuals at different ages.

Because of the importance of the bone mineral status and the water balance of astronauts it is expected that our technique will be used on board manned satellites starting about 1974. The development of instrumentation for this technique should lead to improved instrumentation for the general public and hopefully at a lower cost.

It is worth emphasizing that developments in any scientific area lean heavily on improved technology in other areas of science. In particular the development of new solid state devices in nuclear physics, the development of new radioactive isotopes for nuclear medicine, the development of more stable electronics for various applications have all contributed to the ability to measure bone mineral more precisely and more accurately. It is natural to expect that future developments in technology will also contribute in this way. At the present time, it is also reasonable to consider going from radioisotopes to x-ray tubes as a source of monoenergetic radiation. The state of the art now permits very stable x-ray sources of rather high monochromaticity. Although the initial financial investment in these sources will be somewhat greater than in an equivalent radioisotope source, the savings in the long run and the versatility of energies will more than compensate for this factor.

REFERENCES

1. Price, W. A. The Science of Dental Radiology. Dent. Cosmos 43: 484 (1901).
2. Garn, S. M. An Annotated Bibliography on Bone Densitometry. Am. J. Clin. Nutrition 10 (1): 59-67 (1962).
3. Cameron, J. R., and Sorenson, J. A. Bone Mineral Measurement by Improved Photon Absorption Technique. Conference on Progress in Development of Methods in Bone Densitometry NASA SP-64, Washington, D. C., March 24-27, 1965.
4. Cameron, J. R., and Whedon, G. D., editors; Proc. Conference on Progress in Methods of Bone Mineral Measurement, Spons. by NIH-NIAMD (1970).
5. Cameron, J. R., editor, Proc. Conference on Bone Measurement, Chicago, Ill. USAEC CONF-700515 (1970).
6. Roos, Bengt, et al. in Conference on Bone Measurement, Cameron, J. R., editor. pp 243-254. USAEC CONF 700515 (1970).
7. Ort, M. G. Determination of Vertebral Bone Mineral In Vivo. USAEC Report COO-1422-79 (1970).

APPENDIX I

BIBLIOGRAPHY OF BODY COMPOSITION RESEARCH

UNIVERSITY OF WISCONSIN

1. Cameron, J. R., Grant, R. M., and MacGregor, R., An Improved Technique for the Determination of Bone Mineral Content In Vivo, Radiology 78: 111, (January, 1962). (Abstract).
2. Cameron, J. R., Sorenson, J. A., Measurement of Bone Mineral In Vivo: An Improved Method, Science 142: 230-232, (1963). (Reprint in 1965 AEC Progress Report).
3. Mazess, R. B., Cameron, J. R., O'Connor, R., and Knutsen, D., Accuracy of Bone Mineral Measurements, Science, Vol. 145, 388, No. 3630, (July 24, 1964).
4. Sorenson, J. A. and Cameron, J. R., Body Composition by Differential Absorption by Monochromatic X-rays, Symposium of Low-Energy X- and Gamma Sources and Applications. Institute of Tech. Research, Chicago, Illinois, October 20-21, 1964.
5. Cameron, J. R. and Sorenson, J. A., Improved Instrumentation for Bone Mineral Measurement In Vivo, presented to the First International Conference on Medical Physics, Harrogate, England, Sept., 1965.
6. Cameron, J. R. and Sorenson, J. A., Bone Mineral Measurement by Improved Photon Absorption Technique, Conference on Progress in Development of Methods in Bone Densitometry, NASA, #SP-64, Washington, D. C., March, 1965.
7. Cameron, J. R. and Sorenson, J. A., Bone Mineral Measurement In Vivo Using Monoenergetic Photons from a Radioactive Source, Proceedings of the Symposium on Biomedical Engineering, Marquette University, Milwaukee, Wisconsin, June, 1966.
8. Cameron, J. R. and Sorenson, J. A., The Measurement of Bone Mineral and Body Composition In Vivo, IVth Nordic Meeting on Clinical Physics, Hanko, Finland, September, 1966.
9. Sorenson, J. A. and Cameron, J. R., A Reliable In Vivo Measurement of Bone Mineral Content, The Journal of Bone and Joint Surgery, Vol. 49-A, No. 3, (April, 1967).
10. Clark, J. L., Cameron, J. R. and Sorenson, J. A., A Reliable Method of Measuring Bone Mineral In Vivo, Society of Nuclear Medical Technologists Symposium, Chicago, Illinois, Nov. 1967. (talk)
11. Briggs, R. C., Wilson, E. B. and Sorenson, J. A., Combined Emission-Transmission Scanning of the Skeleton, Radiology, Vol. 90, No. 2, pp. 348-350, (February, 1968).

The following three articles (12, 13, 14) are included in:

Cameron, J.R. and Whedon, G.D., ed., Proceedings of Conference on Progress in Methods of Bone Mineral Measurement, Bethesda, Maryland, Sponsored by NIH-NIAMD, Feb., 1968 (In Press).

12. Cameron, J.R. and Sorenson, J.A., Measurement of Bone Mineral by the Direct Photon Absorption Method: Principles and Instrumentation (also available as USAEC Report COO-1422-21, 1968).
13. Sorenson, J.A., Cameron, J.R. and Mazess, R.B., Measurement of Bone Mineral by the Direct Photon Absorption Method: Experimental Results (also available as USAEC Report COO-1422-22, 1968).
14. Mazess, R.B., Cameron, J.R. and Sorenson, J.A., A Comparison of Radiologic Methods for Determining Bone Mineral Content (also available as USAEC Report COO-1422-23, 1968).
15. Sorenson, J.A. and Cameron, J.R., Measurements of Bone Mineral Content, In Vivo, by Monochromatic Radiation Absorption, Presented to Symposium Ossium, London, England, March 25, 1968.
16. Mazess, R.M., Estimation of Bone and Skeletal Weight by the Direct Photon Absorption Method, From the Symposium on Skeletal Mineralization at the Annual Meeting of the American Association of Physical Anthropologists, Detroit, Michigan, April 24, 1968.
17. Sigmon, B.A., Distribution of Bone Mineral in the Femur, From the Symposium on Skeletal Mineralization, American Association of Physical Anthropologists, April 24, 1968.
18. Cameron, J.R., Mazess, R.B. and Sorenson, J.A., Precision and Accuracy of Bone Mineral Determination by Direct Photon Absorptiometry, Investigative Radiology, 3 (3): 141, (May-June, 1968). (Included in the 1968 USAEC Progress Report).
19. Mazess, R.B., Cameron, J.R. and Sorenson, J.A., Measurement of Skeletal Status; Use of Direct Absorptiometry, Symposium of the Anthropology of Bone, American Association for the Advancement of Science, December, 1968, Dallas, Texas (Talk).
20. Jurist, J.M. and Cameron, J.R., In Vivo Measurement of Bone Quality, Bioengineering Conference, Madison, Wisconsin, March, 1969 (Journal of Biomechanics).
21. Cameron, J.R., et al., Bone Mineral Normative Data, Chicago O'Hare Conference, Chicago, Illinois, April 24, 1969.
22. Witt, R.M., Cameron, J.R. and Schilling, J.P., Bone Standards, Chicago O'Hare Conference, Chicago, Illinois, April 25, 1969 (Abstract).

23. Judy, P.F., Cameron, J.R. and Schilling, J.P., Single Point Measurements of Bone Mineral Content With Two Monoenergetic Photon Beams, Chicago O'Hare Conference, Chicago, Illinois, April, 1969 (Abstract).
24. Sorenson, J.A., Briggs, R.C. and Cameron, J.R., ^{99m}Tc Point Source for Transmission Scanning, Journal of Nuclear Medicine, Vol. 10, No. 5, pp. 252-253, (May, 1969).
25. Cameron, J.R., Jurist, J.M., Sorenson, J.A. and Mazess, R.B., Evaluation of Skeletal Status in Humans, Preprints of the 1969 Annual Scientific Meeting of the Aerospace Medical Association, Aerospace Medical Association, Washington, D.C., pp. 130-131, 1969, text of a paper delivered at the meeting, May 7, 1969, San Francisco, California.
26. Cameron, J.R., Jurist, J.M. and Mazess, R.B., Some Physical Methods of Skeletal Evaluation, Proceedings of the Symposium on Hypogravic and Hypodynamic Environments, June 16, 1969, French Lick, Indiana.
27. Smith, E.L., Jurist, J.M., Babcock, S.W. and Cameron, J.R., Detection of Osteoporosis by Measurement of Monoenergetic Photon Absorption, Eighth International Congress of Gerontology, Abstract Volume, Abstract of a paper delivered at the Congress, August 26, 1969, Washington, D.C.
28. Mazess, R.B., Bone Mineral Content in Wainwright Eskimo: Preliminary Report. Annual meeting of the Am. Assoc. for Advancement of Science. Boston, Mass. Dec, 1969 (also available as USAEC Report COO-1422-77).

The following eight articles (29, 30, 31, 32, 33, 34, 35, 36) are included in:

Cameron, J.R., ed., Proceedings of Bone Measurement Conference, Sponsored by University of Wisconsin Bone Mineral Lab., USAEC CONF 700515 May 22-23, 1970 (In Press).

29. Judy, P.F., Theoretical Accuracy and Precision in the Photon Attenuation Measurement of Bone Mineral (also available as USAEC Report COO-1422-68).
30. Mazess, R.B. and Cameron, J.R., Preliminary Report on a Direct Digital Readout System Absorptiometric Determination of Bone Mineral Content (also available as USAEC Report COO-1422-69).
31. Witt, R.M., Mazess, R.B. and Cameron, J.R., Standardization of Bone Mineral Measurements (also available as USAEC Report COO-1422-70).

32. Mazess, R.B., Ort, M.G., Judy, P.F., and Mather, W.E., Absorptiometric Bone Mineral Determination Using ^{153}Gd (also available as USAEC Report COO-1422-71).
33. Jurist, J.M., Relationship of Ulnar Resonant Frequency, Bone Mineral Content and Various Measures of Body Development in Normal Children (also available as USAEC Report COO-1422-72).
34. Jurist, J.M. and Dymond, A.M., Factors Affecting Reproducibility of Ulnar Resonant Frequency Measurement (also available as USAEC Report COO-1422-73).
35. Mueller, M.N., Cameron, J.R. and Jurist, J.M., The Effect of Rheumatoid Arthritis and Corticosteroid Therapy on Bone (also available as USAEC Report COO-1422-74).
36. Sorenson, J.A. and Mazess, R.B., Effects of Fat on Bone Mineral Measurements (also available as USAEC Report COO-1422-75).
37. Sorenson, J.A. and Cameron, J.R., Transmission Scanning Techniques in Instrumentation in Nuclear Medicine, Vol. II, Orvis and Hine, ed. (In Preparation).

APPENDIX I-A

BIBLIOGRAPHY OF RESEARCH ON
MEASUREMENT OF MECHANICAL PROPERTIES OF BONE

UNIVERSITY OF WISCONSIN

1. Jurist, J.M. and Selle, W.A., Acoustical Detection of Osteoporosis, The Physiologist, 8: 203 (Aug. 1965), abstract of a paper delivered at the 17th Autumn Meeting of the American Physiological Society, August 26, 1965, Los Angeles, California.
2. Selle, W.A. and Jurist, J.M., Acoustical Detection of Senile Osteoporosis, Proceedings of the Society for Experimental Biology and Medicine, 121: 150 (1966).
3. Selle, W.A. and Jurist, J.M., Acoustical Measurement of Bone Density, Federation Proceedings, 25: 577 (Mar. - Apr., 1966, Part I), abstract of a paper delivered at the 50th Annual Meeting of the Federation of American Societies for Experimental Biology, April 15, 1966, Atlantic City, New Jersey.
4. Selle, W.A. and Jurist, J.M., Detection of Osteoporosis by a New Technique, Archives of Physical Medicine and Rehabilitation, 47: 568 (August 1966), abstract of a paper delivered at the 44th Annual Session of the American Congress of Physical Medicine and Rehabilitation, Sept. 1, 1966, San Francisco, California.
5. Selle, W.A. and Jurist, J.M., The Onset of Postmenopausal Osteoporosis as Studied by a New Technique, Journal of the American Geriatrics Society, 14: 930 (1966).
6. Selle, W.A. and Jurist, J.M., Osteoporosis and the Menopause, OB/GYN Digest, 9: 33 (April, 1967).
7. Cameron, J.R., Jurist, J.M., Sorenson, J.A. and Mazess, R.B., Evaluation of Skeletal Status in Humans, Preprints of the 1969 Annual Scientific Meeting of the Aerospace Medical Assoc., Aerospace Medical Association, Washington, D.C., pp. 130-131, 1969, text of a paper delivered at the meeting, May 7, 1969, San Francisco, California.
8. Jurist, J.M., Ulnar Vibratory Properties, Proceedings of the Conference on Progress in Methods of Bone Mineral Measurement, text of a paper delivered at the conference, Feb. 17, 1968, Bethesda, Maryland (In Press).
9. Jurist, J.M. and Wilson, C.R., Estimation of Bone Elasticity, Bone Mineral Conference, Chicago, Illinois, April 24, 1969 (Abstract).
10. Jurist, J.M. and Cameron, J.R., Measurement of Bone Resonant Frequency In Vivo, Proceedings of the Second International Conference on Medical Physics, abstract of a paper delivered at the conference, Aug. 12, 1969, Boston, Mass. (In Press).

11. Jurist, J.M., Smith, E.L., Babcock, S.W. and Cameron, J.R., In Vivo Estimation of Bone Elasticity by Measurement of Ulnar Resonant Frequency, Eighth International Congress of Gerontology, Abstract Volume, abstract of a paper delivered at the congress, August 26, 1969, Washington, D.C. (In Press).
12. Jurist, J.M., In Vivo Determination of the Elastic Response of Bone: I. Method of Ulnar Frequency Determination, Physics in Medicine and Biology, 15: --- (1970).
13. Jurist, J.M., In Vivo Determination of the Elastic Response of Bone: II. Ulnar Resonant Frequency in Osteoporotic, Diabetic, and Normal Subjects, Physics in Medicine and Biology, 15: --- (1970)
14. Jurist, J.M. and Dymond, A.M., Reproducibility of Ulnar Resonant Frequency Measurement, Aerospace Medicine, 41: --- (1970).

The following four articles (15, 16, 17, 18) are included in:

Cameron, J.R., ed., Proceedings of Bone Measurement Conference, Sponsored by University of Wisconsin Bone Mineral Lab., USAEC CONF 700515 May 22-23, 1970 (In Press).

15. Jurist, J.M. and Dymond, A.M., Factors Affecting Reproducibility of Ulnar Resonant Frequency Measurement, pp. 58-67 (also available as USAEC Report COO-1422-73).
16. Jurist, J.M., Relationship of Ulnar Resonant Frequency, Bone Mineral Content, and Various Measures of Body Development in Normal Children, pp. 68-78 (also available as USAEC Report COO-1422-72).
17. Jurist, J.M., Summary of the Data Reduction and Exchange Workshop, pp. 332-333.
18. Mueller, M.N., Cameron, J.R. and Jurist, J.M., The Effect of Rheumatoid Arthritis and Corticosteroid Therapy on Bone, pp. 405-407 (also available as USAEC Report COO-1422-74).
19. Mueller, M.N., Jurist, J.M. and Cameron, J.R., Skeletal Status in Rheumatoid Arthritis, Arthritis and Rheumatism (1970).

ANNUAL PROGRESS REPORTS *

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1. COO-1422-1 Body Composition Determination by Differential Absorption of Monochromatic X-Rays.
. . . J.A. Sorenson and J.R. Cameron.
2. COO-1422-2 Ash Weight vs. Bone Mineral Content by Direct Photon Absorption Technique.
. . . J.R. Cameron, et al.
3. COO-1422-3 Longitudinal Studies of Bone Mineral Content by the Photon Absorption Technique.
. . . J.R. Cameron, et al.
4. COO-1422-4 Factors Affecting the Measurement of Bone Mineral Content by the Direct Photon Absorption Technique.
. . . J.R. Cameron, et al.
5. COO-1422-5 Improved Instrumentation for Bone Mineral Measurement In Vivo. (Presented to the First International Conference on Medical Physics, Harrogate, England, Sept. 1965).
. . . J.R. Cameron and J.A. Sorenson.
6. COO-1422-6 Bone Mineral Measurement by Improved Photon Absorption Technique. (Presented to Conf. on Progress in Development of Bone Densitometry, NASA, Washington, D.C. March, 1965).
. . . J.R. Cameron and J.A. Sorenson.

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ANNUAL PROGRESS REPORTS

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J.R. Cameron.
2. COO-1422-8 Body Composition Determination by Differential
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. . . J.A. Sorenson and J.R. Cameron.
3. COO-1422-9 Progress in Development of a Bone Equivalent
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. . . J.A. Sorenson, R.M. Witt and J.R. Cameron.

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... E.L. Smith, J.R. Cameron and J.A. Sorenson.
3. COO-1422-12 Effect of the Measurement of Bone Mineral of
I-126 Contamination of I-125.
... P.F. Judy, J.R. Cameron and J.A. Sorenson.
4. COO-1422-13 Precision and Accuracy of Bone Mineral Determination.
... R.B. Mazess, J.R. Cameron and J.A. Sorenson.
5. COO-1422-14 Instruction Manual for Semi-Automatic Bone
Measuring System.
... R.M. Witt, P.F. Judy, J.R. Cameron and J.A.
Sorenson.
6. COO-1422-15 Reliability of Measuring Changes in Bone Mineral
Content as a Function of the Precision of the
Measurement.
... J.A. Sorenson and J.R. Cameron.
7. COO-1422-16 Data Recording System for Bone Mineral Measurements.
... J.A. Sorenson and J.R. Cameron.
8. COO-1422-17 Bone Mineral Content as a Function of Bone Diameter
in Cortical Bone.
... J.A. Sorenson, A.S. Raffii and J.R. Cameron.

9. COO-1422-18 A Moldable Soft Tissue Equivalent Material.
. . . S. Suntharalingam, P.F. Judy, R.M. Witt,
J.R. Cameron and J.A. Sorenson.
10. COO-1422-19 Modification to Computer Program To Determine
Bone Mineral Content.
. . . R.M. Witt, A.S. Raffii, J.R. Cameron and
J.A. Sorenson.
11. COO-1422-20 A Reliable In Vivo Measurement of Bone Mineral
Content (Reprint from The Journal of Bone and
Joint Surgery, Vol. 49-A, No. 3, pp. 481-497,
April, 1967).
. . . J.A. Sorenson and J.R. Cameron.

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... J.R. Cameron and J.A. Sorenson.
2. COO-1422-22 Measurement of Bone Mineral by Direct Photon Absorption Method: Experimental Results.
... J.A. Sorenson and J.R. Cameron.
3. COO-1422-23 A Comparison of Radiological Methods for Determining Bone Mineral Content.
... R.B. Mazess, J.R. Cameron and J.A. Sorenson.
4. COO-1422-24 Transmission Scanning with Tc-99m and Cs-137.
... J.A. Sorenson and R.C. Briggs.
5. COO-1422-25 Remineralization of a Fractured Tibia.
... E.L. Smith, J.L. Clark and J.R. Cameron.
6. COO-1422-26 Comparison of I-125, Pb-210 and Am-241 as Radiation Sources for Bone Mineral Measurement.
... J.A. Sorenson and J.R. Cameron.
7. COO-1422-27 Bone Mineral Measurement with a Line Printer Output and Desk-top Calculator Computations.
... J.L. Clark and J.A. Sorenson.
8. COO-1422-28 Program for Bone Mineral Computations Using General Electric Time-Sharing Service.
... K. Kianian and J.A. Sorenson.

9. COO-1422-29 Bone Mineral Content and Diameter vs. Age in the Radius and Humerus of Normal Subjects.
. . . J.A. Sorenson, R.B. Mazess, E.L. Smith, J.L. Clark and J.R. Cameron.
10. COO-1422-30 Estimation of Bone and Skeletal Weight by the Direct Photon Absorptiometric Method (From the "Symposium on Skeletal Mineralization" at the annual meeting of the Am. Assoc. of Physical Anthropologists, Detroit, Michigan, 1968).
. . . R.B. Mazess.
11. COO-1422-31 Distribution of Bone Mineral in the Femur (From the "Symposium on Skeletal Mineralization", Am. Assoc. of Physical Anthropologists, Detroit, Michigan, April 24, 1968).
. . . B.A. Sigmon.
12. COO-1422-32 Precision and Accuracy of Bone Determination by Direct Photon Absorptiometry.
. . . J.R. Cameron, R.B. Mazess and J.A. Sorenson.
13. COO-1422-33 The Effects of Physical Activity on Bone (Presented at the "Symposium on Skeletal Mineralization", Am. Assoc. of Physical Anthropologists, Detroit, Michigan, 1968).
. . . E.L. Smith, Jr. and W.L. Felts.
14. COO-1422-34 In Vitro Measurements of Bone Volume by Air Displacement.
. . . E.L. Smith, W.G. Kempke, A. Seireg and J.R. Cameron.
15. COO-1422-35 Radiation Effects on Bone Mineral Content.
. . . S.P. Bartok, R.M. Witt and J.R. Cameron.

16. COO-1422-36 Construction of an Iodine-125 Photon Source
Using an Improved Source Holder.
. . . R.M. Witt, J.A. Sorenson and J.R. Cameron.
17. COO-1422-37 An Estimation of Variance of Bone Mineral Content
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. . . P.F. Judy, J.A. Sorenson and J.R. Cameron.
18. COO-1422-38 A Description of the Bone Mineral Content Measure-
ment with a Modulation Transfer Function.
. . . P.F. Judy, J.R. Cameron and J.A. Sorenson.
19. COO-1422-39 A Portable Scanning System with Direct Readout
for Absorptiometric Determination of Bone Mineral
Content.
. . . R.B. Mazess and J.R. Cameron.
20. COO-1422-40 An Improved Linear Bone Mineral Scanner.
. . . R.M. Witt, J.A. Sorenson and J.R. Cameron.

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... J.R. Cameron.
2. COO-1422-42 Bone Standards.
... R.M. Witt and J.R. Cameron.
3. COO-1422-43 New Methods of Skeletal Status Evaluation in Space Flight, Aerospace Medicine, 1969, in press.
... J.R. Cameron, J.M. Jurist, J.A. Sorenson and R.B. Mazess.
4. COO-1422-44 Some Physical Methods of Skeletal Evaluation, Proceedings of the Symposium on Hypogravic and Hypodynamic Environments, text of a paper delivered at the symposium, June 16, 1969, French Lick, Indiana, in press.
... J.R. Cameron, J.M. Jurist and R.B. Mazess.
5. COO-1422-45 A Coding System for Clinical and Normative Studies.
... J.M. Jurist, J.L. Fischer and K. Kianian.
6. COO-1422-46 Quantitative Evaluation of Skeletal Status in the Rheumatic Diseases.
... J.M. Jurist, M.N. Mueller and J.L. Fischer.
7. COO-1422-47 In Vivo Determination of the Elastic Properties of Bone:
I. Theory, Apparatus and Method of Ulnar Resonant Frequency Determination, 1969, in press.
... J.M. Jurist.

8. COO-1422-48 In Vivo Determination of the Elastic Properties of Bone: II. Resolution and Precision of the Ulnar Resonant Frequency Determination, 1969, in press.
. . . J.M. Jurist.
9. COO-1422-49 In Vivo Determination of the Elastic Properties of Bone: III. Ulnar Resonant Frequency in Osteoporotic, Diabetic, and Normal Subjects, 1969, in press.
. . . J.M. Jurist.
10. COO-1422-50 In Vivo Measurement of Bone Quality, text of a paper delivered at the Symposium on Bioengineering in Wisconsin, March 6, 1969, Madison, Wisconsin.
. . . J.M. Jurist and J.R. Cameron.
11. COO-1422-51 An Improved Apparatus for Determination In Vivo of Bone Resonant Frequency by Recording the Vibration Response Spectrum.
. . . J.M. Jurist, D. Loper and C. Vought.
12. COO-1422-52 Dynamic Measurement of Young's Modulus for Excised Strips of Bone.
. . . C.R. Wilson and J.M. Jurist.
13. COO-1422-53 Study of Bone Strain by Holographic Interferometry.
. . . J.M. Hevezi.
14. COO-1422-54 Bone as the Resonant Element in a Feedback Oscillator.
. . . C.R. Wilson, C. Vought and J.R. Cameron.
15. COO-1422-55 Body Composition by Absorptiometry of Monoenergetic Radiation.
. . . R.B. Mazess, J.R. Cameron and J.A. Sorenson.

16. COO-1422-56 A Portable Unit for Determination of Bone Mineral Content by Photon Absorptiometry.
. . . R.B. Mazess and J.R. Cameron.
17. COO-1422-57 Bone and Soft-Tissue Changes During Protein-Calcium Restriction.
. . . R.B. Mazess.
18. COO-1422-58 Evaluation of Radionuclide Sources for Transmission Scanning.
. . . J.A. Sorenson and J.R. Cameron.
19. COO-1422-59 Computer Programs for Bone Mineral Calculations.
. . . K. Kianian.
20. COO-1422-60 A Dichromatic Absorption Method for the Measurement of Bone Mineral Content.
. . . P.F. Judy and J.R. Cameron.
21. COO-1422-61 Report of the First Bone Mineral Scanning Conference.
. . . J.R. Cameron.
22. COO-1422-62 A Quantitative Measure of Skin Transparency in Relation to Osteoporosis.
. . . J.R. Cameron, G. Fullerton and M.N. Mueller.
23. COO-1422-63 An Improved Method of Repositioning Distal End Sites on the Linear Bone Mineral Scanner.
. . . M. Binder, J.L. Fischer and J.A. Sorenson.
24. COO-1422-64 Bone Mineral Determination: Radiographic Photodensitometry and Direct Photon Absorptiometry.
. . . R.B. Mazess and C. Colbert.
25. COO-1422-65 Preliminary Report: Bone Mineral Content of Wainwright Eskimo.
. . . R.B. Mazess.

26. COO-1422-66 ^{99m}Tc Point Source for Transmission Scanning (reprint).
... J.A. Sorenson, R.C. Briggs and J.R. Cameron.
27. COO-1422-67 Detection of Osteoporosis by Measurement of Monoenergetic
Photon Absorption.
... E.L. Smith, S.W. Babcock and J.R. Cameron.

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. . . R.B. Mazess and J.R. Cameron.
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. . . R.M. Witt, R.B. Mazess and J.R. Cameron.
4. COO-1422-71 Absorptiometric Bone Mineral Determination Using ¹⁵³Gd.
. . . R.B. Mazess, M.G. Ort, P.F. Judy, and W. E. Mather.
5. COO-1422-72 Relationship of Ulnar Resonant Frequency, Bone Mineral Content, and Various Measures of Body Development in Normal Children.
. . . J.M. Jurist.
6. COO-1422-73 Factors Affecting Reproducibility of Ulnar Resonant Frequency Measurement.
. . . J.M. Jurist and A.M. Dymond.
7. COO-1422-74 The Effect of Rheumatoid Arthritis and Corticosteroid Therapy on Bone.
. . . M.N. Mueller, J.R. Cameron and J.M. Jurist.
8. COO-1422-75 Effects of Fat on Bone Mineral Measurements.
. . . J.A. Sorenson and R.B. Mazess.

9. COO-1422-76 Tissue Changes Following Venous Occlusion Using Photon Absorptiometry.
. . . R. B. Mazess.
10. COO-1422-77 Bone Mineral Content in Wainwright Eskimo: Preliminary Report.
. . . R. B. Mazess (Presented at the Am. Assoc. for Advancement of Science meeting held in Boston, Mass., Dec. 1969).
11. COO-1422-78 An Improved Bone Standard Containing Dipotassium Phosphate Solution for the Intercomparison of Different Transmission Bone Scanning Systems.
. . . R. M. Witt and J. R. Cameron.
12. COO-1422-79 Determination of Vertebral Bone Mineral In Vivo.
. . . M. G. Ort and J. R. Cameron.
13. COO-1422-80 The Bone Mineral Content of the Phalanx of Chronic Hemodialysis Patients.
. . . P. F. Judy, C. J. Beirne and J. R. Cameron.
14. COO-1422-81 Mineral Content and Compressive Strength of Cancellous Bone.
. . . C. R. Wilson, S. Disterhoft and J. R. Cameron.
15. COO-1422-82 Evaluation of Radionuclide Sources for Transmission Scanning (not included, available by request - Invest. Rad. 5: 92 (1970)).
. . . J. A. Sorenson.
16. COO-1422-83 Review of Body Composition Research at the University of Wisconsin 1960-1970.
. . . J. R. Cameron.

17. COO-1422-84 In Vivo Determination of the Elastic Response of
Bone: I. Method of Ulnar Resonant Frequency
Determination. (Phys. Med. Biol. (1970) in press).
. . . . J. M. Jurist
18. COO-1422-85 In Vivo Determination of the Elastic Response of
Bone: II. Ulnar Resonant Frequency in Osteoporotic,
Diabetic, and Normal Subjects. (Phys. Med. Biol.
(1970) in press).
. . . . J. M. Jurist
19. COO-1422-86 Reproducibility of Ulnar Resonant Frequency
Measurement. (Aerospace Medicine (1970) in press).
. . . . J. M. Jurist and A. M. Dymond

APPENDIX III

Individuals Who Have Contributed to Bone Mineral and Body Composition Research at the University of Wisconsin 1960 - 1970

Graduate or Medical Students Trained on the Project

R. M. Grant, Ph.D.
R. MacGregor, Ph.D.
J. A. Sorenson, M. S. * +
R. O'Connor, M. D.
D. Knutsen, M. D.
P. F. Judy, M. S. * +
R. M. Witt, M. S. * +
J. English, Ph. D.
E. L. Smith, M. S. * +
F. Lin, M. S.
G. Fullerton, M. S. *
C. R. Wilson, M. S. * +
M. G. Ort, M. S. *
W. E. Mather, B. S. *
J. Sandrik, B. S. *

Professional People (M.D.'s or Ph.D.'s) Associated with the Project

J. R. Cameron, Ph.D. *
R. B. Mazess, Ph.D. *
J. M. Jurist, Ph.D. *
S. Babcock, M. D. *
J. Huffer, M. D. *
M. N. Mueller, M. D. *

Technical People Associated with the Project

S. Suntharalingam
K. Moses
C. Bogenholm
A. S. Raffii
J. L. Fischer *
F. Binder
K. Kianian *
S. I. Kennedy *

* Still on project

+ Expect to get Ph.D. within 1 year