INFANT AND CHILD ANTHROPOMETRY

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Body size information has long been the subject of a large number of longitudinal and cross-sectional studies by physicians and bioanthropologists. The emphasis has primarily been concerned with pediatric problems or nutritional, genetic, environmental, or socio-cultural implications of growth and development, and has rarely been concerned with applied measurements.

Yet, data on current populations of infants and children is of increasing importance to industrial designers and manufacturers of toys, restraint systems, furniture, clothing, and other child products, as well as various governmental agencies responsible for establishing new child safety standards. (1-3) Those involved with these practical applications of child measurement data have been concerned with the dearth of useful data related to basic dimensional measures. The interest of this paper is to review the extent, nature and outline the new techniques and equipment being utilized by The University of Michigan in a current nationwide anthropometric study of U.S. infants and children.

In a recent review of the infant and child measurement literature, over 800 studies were referenced. (4) In this publication, "Source Data of Infant and Child Measurements; Interim Data, 1972", tabulations were provided for selected specific measurements, such as "arm length" or "sitting height". This extensive review of the existing literature indicated a number of limitations in usage of available data as well as documented the complete lack of many needed functional measures, concurring with previous surveys of child measurement data. (5-10) Data were selected from 35 studies conducted from 1929 through 1972. However, only one-third of these were done in the preceding 10 years. Since many growth studies indicate that children have been getting larger, early studies may not be truly representative of current populations. Some measurement data pertain only to highly selected populations, such as white Philadelphia school children, which may not be representative of the whole U.S. population. Regional variations, as well as socio-economic, nutritional, and ethnic or racial variations have been found.

The user of child anthropometric data should also be aware of a number of limitations in the data. While the literature is profuse with information on

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stature and weight, evaluation has revealed that often these measures were taken by different techniques, and often by a multitude of measurers (often untrained) in the same study. In addition, a large number of measurements were found to be poorly defined, not reproducible, incorrectly measured, and of questionable accuracy. In many longitudinal studies new subjects were added in the middle of a study as old subjects were lost. Many studies are not directly comparable, not only because of differences in precisely defining measurement (or not specifying at all), but because of age differences. While age 5 in one study may mean exactly 5 years post-birth another study may include subjects from 4 1/2 to 5 1/2 years; or, in another, age 5 may mean from age 5 to 6 years. Such discrepancies may provide a number of problems to the user of anthropometric data on children, particularly if the validity and applicability of each source is not carefully examined.

This comprehensive review of the child and infant anthropometry data available to date shows that while large numbers of limited studies have been conducted, including routine clinical measurement of a few measures such as body weight, stature, and chest or head circumference, the type of dimensional data urgently needed for a number of current safety applications is non-existent. To date, no body of data has been published which validly describes such functional measures as the range of size opening an infant or child's hand or fist can penetrate for various "age" levels, the distance the arm or leg can extend, or the size opening the buttocks can slide through. In addition, no single study appears to exist which can provide current body dimensional information on infants and children from birth through pre-puberty on a representative nationwide basis (taking into account such factors as regional, ethnic, racial, socio-economic-cultural, nutritional, and other differences).

The need for such information is evident and particularly critical in areas related to product safety design. It has been estimated by the U.S. Public Health Service that toys injure 700,000 children each year, (11) and many such injuries are due to hazards resulting from non-existing or improper physical design standards allowing physical ingestion or other mechanical hazards. Designers of children's toys, equipment, or furniture have had only limited information for use in determining safe dimensions. No valid information is known to be available for such practical things as bicycle handbrakes, the size, shape, and size ranges of objects liable to become stuck in the larynx, or the opening diameter and throat distance of a meat grinder to provide protection against a child's hands getting caught. Numerous other examples of needed measurement data have been identified by the National Commission on Product Safety's analysis of common products associated with injuries and fatalities. (12)

The design of child restraint devices offers one example of the need for unique packaging based upon the particular body dimensions, organ relationship and other structural differences of child or infant occupants. Since the child has often been treated as a "miniature adult" by the design engineer, Burdi, et al. (1969) (13) published a guide providing pediatric and anatomical considerations for proper design of child restraints. This paper stressed that the infant and child differ structurally from the adult in a number of ways which are critical to the design for protection against impact forces and for adequate occupant restraint systems. Problems which relate to child restraint systems include basic differences in child-adult structure, center of gravity of the seated or inclined body, the head mass in relation to the neck and general body proportions, positions, relative size and exposure of key organs, and biomechanical properties of tissues.

Child or infant anthropomorphic dummies used in dynamic tests of child restraint systems to date have severely limited validity as human surrogates, since none are based upon adequate knowledge of the infant's or child's structural, anthropometric, or functional measures. The most recent federal standard (FMVSS 213) of 1 March 1974 related to child restraints specifies "either the Sierra 3-year-old P/N 492-03, or the Alderson Model #V 1P-3C" for the 17 to 43 pound weight range, and "either the Alderson Model #V 1P-6C, of (sic) the Sierra 6-year old P/N 492-106" for dummy tests in the over 43 pounds range. (1) Although specifications for a dummy representing a 6-month-old infant are preliminary, the new federal standard states "In the case of restraints recommended for children of 17 pounds or less, the dummy would represent a 6-month-old child and be of soil-cloth construction, filled with plastic pellets and lead shot. This total weight would be 17.4 pounds, with a head weight of 3.5 pounds." (1) While ideally such devices can serve a useful purpose as a standardized test tool, results using such "child" anthropomorphic dummies which do not represent biological systems cannot be validly interpreted in relation to injury, as has been attempted in one recent publication. Further, the original source of anthropometric design information utilized by the manufacturers of current child dummies is not clear. Infant "dummies" used in current research may be described as of questionable validity. General Motors, for example, used a toy doll purchased from a local department store and constructed of a plastic head, arms and legs, and rag joints. The doll was weighted with lead to simulate weight distribution of an infant. It was noted that "although the doll was not very sophisticated, it proved to be the best infant dummy available for test purposes." (14) As for dummies of 3- and 6-year-olds; even the test engineers recognize they have some limitations: "...their joints are poorly articulated and their range of motion is very restricted". (15) This limits the value of kinematic studies with these dummies.

Recently concern has been expressed relative to current U.S. belt interlock restraint systems, which were previously designed and tested for adult use. Children weighing less than 47.3 lbs (50th percentile 6-year-old child) can be transported unrestrained. Although several groups have expressed the opinion that the upper torso belt could be injurious to children in a collision if it did not fit the child properly, there appears to be no evidence to substantiate such concern at present, although child impact data are very limited. (16)

The University of Michigan Study

In 1972, under sponsorship of the Children's Hazards Division of the Bureau of Product Safety, and continued by the Consumer Product Safety Commission, the authors initiated a three-year nationwide anthropometric study of infants and children up to 12 years of age. (17) This was designed as a multi-disciplinary study, with the co-investigators representing the Biomedical Department, Highway Safety Research Institute, and the Department of Anthropology; the Department of Pediatrics of the School of Medicine; and the Department of Electrical Engineering, College of Engineering. This basic specialization in physical anthropology , bioengineering, and mini-computers was augmented by advisors from the Center for Human Growth and Development;

the Department of Biostatistics, School of Public Health; and Developmental Anatomy, School of Medicine. The initial phase was devoted to design and development of new anatomical measurement devices. This study is presently completing the data collection phase, and it is anticipated that data analysis and a final report will be completed within the next six months. In all, 41 different measurements have been taken on over 3000 children, from age two weeks to 12 years, representative of the U.S. population (using HEW and U.S. census data, by geographic distribution, sex, race, and parents' economic, educational, and occupational status).

Eight different measurement devices are being utilized, including highly modified anthropometers, sliding calipers, girth measurement devices, devices to measure inside and outside hand grip, finger and minimum hand dimensions, and separate devices for infant and child center of gravity. Two portable field measurement systems were developed, one providing a remote digital readout capability, and the other interfacing the instruments through a 16 channel analog to digital converter to a portable mini-computer system. The digital system can be carried by one individual and is cased in two portable lightweight cases. The total computerized system is portable and is transported easily to field locations (Fig. 1).

Fig. 1. The complete mini-computer (NOVA 1220) anthropometric system is designed for portability. The case on the right carries all measuring instruments, and the keyboard, terminal , and complete data acquisition system is contained on the left.

A major source of error in attempting measurement of infants or children with a standard anthropometer is the lack of skeletal landmarks and thus the lack of means of reproducing a measurement accurately in soft tissue. Therefore, both sliding calipers and anthropometers were designed to measure both pressure and distance simultaneously. This was accomplished by locating a pressure transducer in the plexiglass "paddle" blade, and incorporating a 10-turn potentiometer connected by a pulley and a cable system to the movable blade for an electrical readout of the precise length. This equipment is calibrated daily before use, and checked periodically. The modified sliding calipers and anthropometer are shown in Figs. 2 and 3.

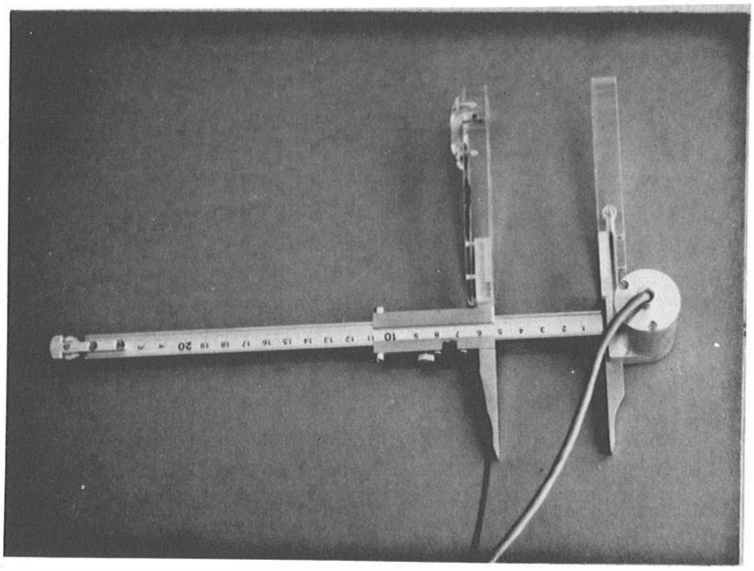

Fig. 2 Modified sliding calipers

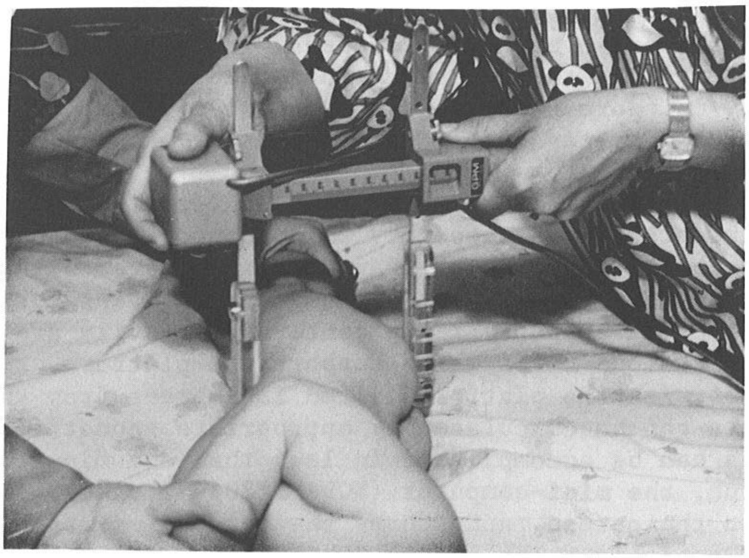

Fig. 3 Infant buttock measurement with modified anthropometer

A third major modification involved converting the standard measuring tape to an automatic device (Fig. 4). This evolved through four modifications, the 3rd and 4th generations being illustrated. A hand grip allows comfortable placement of the measurer's hand. With the other hand, the tape is pulled out and around the part of the body to be measured, the end being attached back on the instrument. An electrical signal proportioned to the length of tape in the closed loop is provided by the instrument. Tension may be controlled by the operator's thumb on the pulley, which is attached to a coil spring internally, or may be controlled automatically by the computer providing a predetermined tension for each measurement. This feature allows a precise standardization of circumference measures. Each of these devices is controlled by

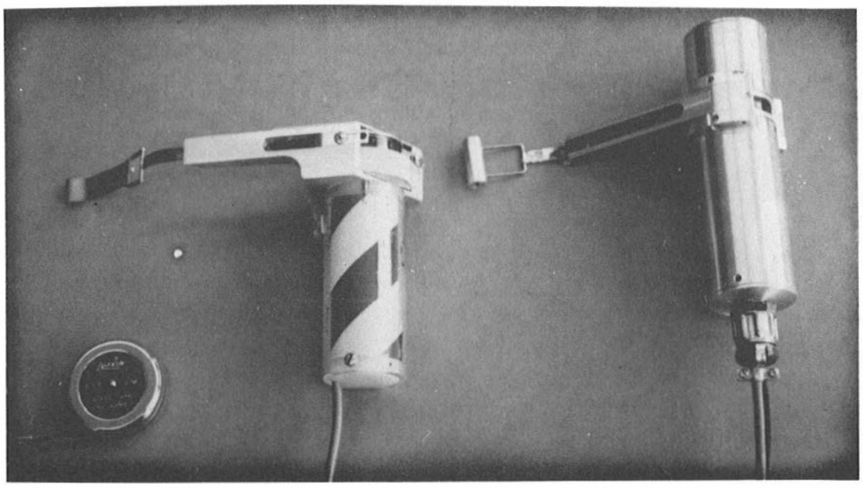

Fig. 4 Three generations of girth measurement devices. The most recent modification on the right.

a switch on the handle which is pushed by the index finger when the operator wishes to record. In the case where the digital readout system is used without a computer an arbitrary pressure value of 0.5 $lb./in^2$ has been established. However, in the computer-controlled system, pressure values between 0 and 2 $lb./in.^2$ are recorded. Thus, paired values of distance and simultaneous pressure are available for data storage and subsequent analysis.

Two separate devices measure whole-body center of gravity in 3 dimensions, one for infants (with a capacity to 50 pounds), and one for older children (to 200 lbs.). Centers of gravity are measured with the subject positioned both standing (lying supine) and seated (lying horizontal with legs over an adjustable support). The centers of gravity are determined by measurement of three load cells which support the platform, followed by a repeat measurement with the platform tilted 15 degrees from the horizontal. C. G. measurements can be calculated by appropriate geometric relations, and all positions can be accomplished in less than one minute. Upon completion of the run, the mini-computer (NOVA 1220) provides computation and visual display on the screen, and stores the data on magnetic tape for future statistical analysis. The infant C. G. device consists of a clear plexiglass tilt-table contoured surface which the infant is placed upon (Fig. 5). The adjustable leg board is also clear Lexan(R). Load cells are built into each of the three right supports. The child C. G. device, as illustrated (Fig. 6), is constructed quite differently, although the principle

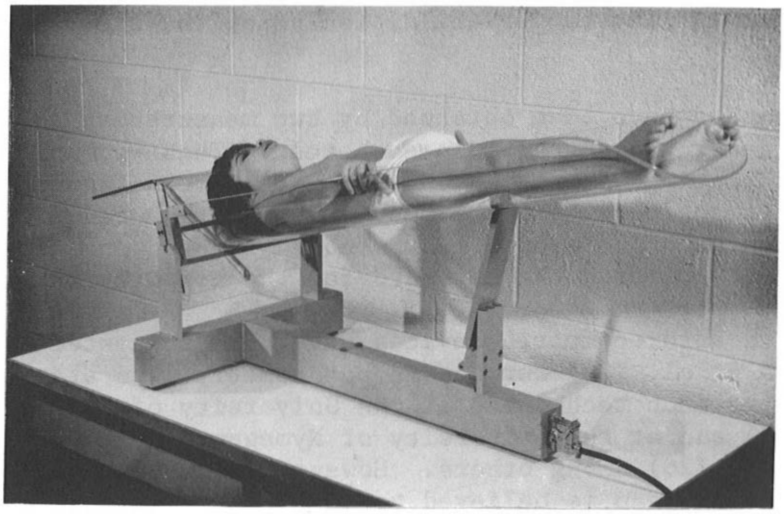

Fig. 5. The infant center of gravity device with platform tilted 15° from the horizontal.

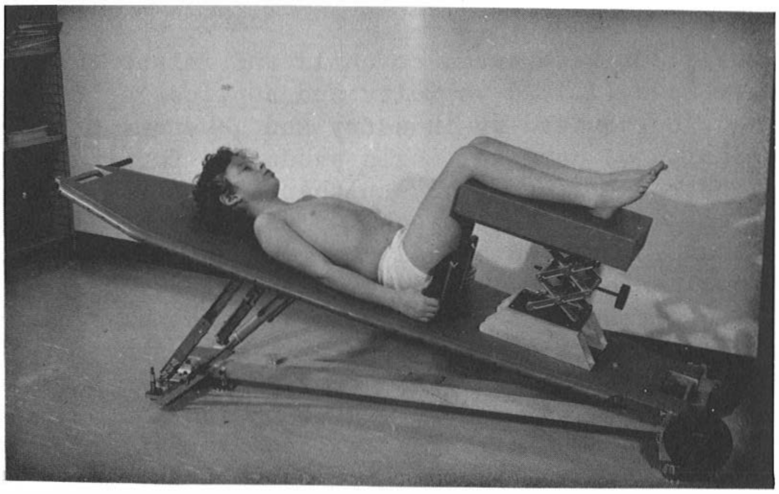

Fig. 6. The child center of gravity device in the seated position with platform tilted 15° from the horizontal.

remains the same. These devices represent a considerable advance over previous center of gravity devices in portability as well as accuracy and speed. These instruments are described elsewhere in detail (18-21).

Other devices are used to obtain functional measures of grip, hand and finger dimensions, and a special grip cone allows measurement of both inside and outside grip dimensions. The size hole which the index, middle, and little finger can get through is measured with a plastic device containing various sized holes. Various plexiglass hole boards with a hinged attachment to ensure that hands do not get stuck are used to determine what size opening a child can put his hand through.

Of the 41 infant measurements, most have not been previously measured. For both infants and children a large number of functional measurements are obtained for direct application to applied problems. All measurements are taken in about 12 minutes per child, including the time necessary to undress and dress each.

Measurements have been obtained by two measurement teams consisting of two female research assistants in each team. These women were highly qualified for interacting with children, two having been former teachers. Only one member of each team took the measurements, thus reducing the chance of measurement error. The second team member assisted and either recorded the digital data or operated the keyboard for the computerized system.

Automated anthropometric devices have been suggested (22-23) and developed by Garn et al. (24) for use in odontometry, and at present work is being conducted using such techniques at the University of Queensland, Brisbane, Australia (25) and at the University of Nymegen, the Netherlands, by Prahl-Anderson et al. (26) among others. However, the current system in use by The University of Michigan is believed to be the most extensive systematic use of automated anthropometry, the first use of the NOVA mini-computer data acquisition system, and the first practical portable computerized means of obtaining C.G. measures on both children and infants.

CONCLUSIONS

Although over 800 references to child and infant anthropometry are in the literature, most have limited validity and application to current populations. Functional measures required by industry and government for federal safety standards for design of dummies, child products, furniture, or protective devices such as restraint systems have either been incomplete, inadequate, or nonexistent. Some of the limitations influencing validity of existing data have been outlined for the potential user. As a start toward obtaining necessary functional anthropometric data, The University of Michigan is currently conducting a study sponsored by the U. S. Consumer Product Safety Commission to obtain valid nationwide measurements on a representative U.S. population from birth to age 12 years. In this study some 41 measurements, including many functional measures, as well as seated and supine whole-body centers of gravity, are being taken utilizing a new automated anthropometric mini-computer system. A number of specialized infant and child measurement devices have been designed and used with pressure transducers providing a new basis for more accurate and precise measurement of body dimensions than has been possible with previous standard anthropometric instruments. This information has already provided a basis for an improved federal safety standard for infant crib slat width. (27-28).

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