Carpal bone maturation during childhood and adolescence: Assessment by quantitative computed tomography

Preliminary results

F. Canovas¹, M. Jaeger², A. Couture³, Ch. Sultan⁴ and F. Bonnel¹

¹ Laboratoire d’Anatomie, Faculté de Médecine de Montpellier; Orthopédie 3, Hôpital Lapeyronie, CHU Montpellier, F-34000 Montpellier, France
² Corpus 2000, Unité de Modélisation, Cirad, F-34000 Montpellier, France
³ Unité de Radiologie Pédiatrique, Hôpital Arnaud de Villeneuve, CHU Montpellier, F-34000 Montpellier, France
⁴ Unité d’Endocrinologie Pédiatrique, Hôpital Arnaud de Villeneuve, CHU Montpellier, F-34000 Montpellier, France

Summary: The aim of our study was to measure the volume of each carpal bone during childhood and adolescence by image processing from computed tomography (CT) scans, and to analyze the relationship between the eight carpal bones. Thirteen CT scans were performed in nine normal prepubertal, peripubertal and post-pubertal children, six boys and three girls, aged 5-14 years. Each scan was processed in order to extract the carpal bones. The volume was computed for each bone. There was a significant correlation between carpal bone volume and age (0.55< r< 0.79), and a very strong correlation between the volume of a given carpal bone and the volume of all the others, whatever the age (0.87< r< 0.99, p< 0.01). Image processing is a potentially useful method for assessing bone maturation. The constant ratio between carpal bone volumes indicates that these bones interact with each other in wrist bone maturation.

Maturation des os du carpe pendant l’enfance et l’adolescence : analyse quantitative d’images tomodensitométriques - Résultats préliminaires

Résumé : Le but de notre étude était de mesurer le volume de chaque os du carpe au cours de l’enfance et de l’adolescence par analyse des images d’examens tomodensitométriques (TDM) du poignet, et d’analyser les relations entre les huit os du carpe. Treize TDM ont été réalisés chez 9 enfants en période prépubertaire, pubertaire et postpubertaire, 6 garçons et 3 filles, âgés de 5 à 14 ans. Les os du carpe ont été isolés les uns des autres sur chaque examen TDM et leurs volumes ont été calculés. Nous avons retrouvé une relation significative entre le volume des os du carpe et l’âge (0,55< r < 0,79), et une relation très significative entre le volume d’un os du carpe et le volume des autres os du carpe, quel que soit l’âge (0,87< r < 0,99, p<0,01). L’analyse d’image est une méthode intéressante pour évaluer la maturation osseuse. Le rapport constant entre le volume des os du carpe, quel que soit l’âge, semble indiquer que les os du carpe interagissent entre eux durant la maturation osseuse du poignet.

Key words: Bone maturation – Carpal bone – Volume – Computed tomography

The prediction of a child’s final height as an adult and, more generally, the monitoring of growth are part of the concerns of both pediatricians and orthopedic surgeons. Ever since Greulich and Pyle [7], and Tanner [13] demonstrated the high correlation between bone maturation and growth, bone age has been the standard method used in clinical practice, despite certain imperfections. Bone age is determined from an X-ray of the left hand and wrist. Even with computer-assisted assessment, this method requires long experience with X-ray interpretation [5, 10]. This study was designed to assess bone maturation by image processing, a method by which radiologic data are converted to numerical data, and thus the qualitative analysis becomes quantitative [9]. The wrist was selected as it is a usual skeletal site for evaluation of bone age; it also provides the possibility of studying several bones that appear at different times, as reported by Greulich and Pyle [7]. Specific software tools were developed to extract and then separately measure the volume of each carpal bone from the CT wrist scans. The aim of our study was to measure the volume of each carpal bone from CT scans during childhood and adolescence and to analyze the relationship between the eight carpal bones during bone maturation.

Materials and methods

The study was performed in nine normal prepubertal, peripubertal and postpubertal children, six boys and three girls, aged 5 to 14 years. Informed consent was obtained from parents. Wrist CT scans...
were performed on one side in five children and on both sides in four children.

Data acquisition was done on a General Electric helicoidal CT HiSpeed scanner. The following acquisition protocol was used for every scan: tube parameters were defined by a standard bone acquisition protocol: kV 140, mA 190, 1s; tube orientation was axial (swivel=0, tilt=0); helix step was fixed at 3 mm and Dfov at 10 cm centered on the subject’s wrist; image reconstruction was performed on a 512 by 512 matrix with collapsing slices of 1 mm width; wrist over the head was oriented for axial scan acquisition and no specific filter or zoom factor was used (pixel size was 100/512 mm on both X and Y axes).

Original reconstructed images were sent through a UNIX work-station, where images were copied on floppy disks to be processed with C2000 software on a graphic work-station. We then worked on the image digital values. Each pixel value, corresponding to its CT reconstructed X-ray absorption coefficient (density value or CT number) was encoded on 12 bits, allowing a range of 4095 density values. Value 0 was set to be the air response and 1024 the water response; conversion to the Hounsfield scale was easily obtained by subtracting 1024 from the density values.

Each scan was processed in order to extract the wrist carpal bones. This task was achieved by the following procedures (Fig. 1). The first was image thresholding. Density values from 1250 to 4095 were retained in the current scanned image [3]. The second procedure was connected components processing [4]. Each connected region was labeled, including non-bony tissue regions. Thus, holes in bone regions were automatically detected and filled. The third procedure was to clean small bone tissue regions. Regions with an area of less than 4 pixels (0.16 mm²) were removed; these usually corresponded to artifacts. The fourth procedure was to clean the edges of each bone region using a single topologic procedure.

These procedures composed a single task that was automatically run by a script on each image. The investigator then verified that all relevant bone tissues had been completely detected using a 3D reconstruction wireframe visualization. Some regions were not completely closed or two different bones were merged in a single region. These cases were corrected with the help of an edge detection filter [6].