Clinical communication

Cardiovascular observations on Tarahumara Indian runners—the modern Spartans*

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Cardiologists have become increasingly interested the last few years in the effects of physical conditioning on the cardiovascular system. The thought has been that, in general, our present-day civilization (whose benefits we certainly do not decry) may be leading us into a more and more sedentary type of life to the detriment of certain basic adaptive mechanisms, including those regulating function of the heart. Moreover, it has been contended, largely on clinical grounds, that we might beneficially utilize various regimens of deliberate physical conditioning to forestall the ravages of ischemic heart disease, or even to improve the prognosis once that disease has become manifest.

Life has of course not always gone on so comfortably for *Homo sapiens*. What aeons of our primordial ancestors did with their stones and clubs and caves we can only surmise. But we do have in recorded history a high state of physical culture and development achieved by the ancient Spartans who, it will be recalled, took children from their parents at an early age for years of intensive training in physical feats now legendary. That their incentive was survival itself (in the more or less constant combat which they waged with the Athenians for several centures B.C.) doubtless accounted in large part for the "Spartan constitution." Theirs was perhaps history's most illustrious chapter of physical attainments and prowess before the human brain supplanted muscle as man's dominant means of conquest of his environment and of his fellow man.

A modern counterpart of the Spartans is found in a little known tribe of Indians, variously estimated to number from 30,000 to 50,000, residing in an isolated area of mountains encompassing the continental divide of northern Mexico. Their name, Tarahumara, probably a corruption of "Raramuri," liberally translated from their language means "fleet foot" or "foot runner," and their habitat for perhaps 2,000 years has been in and around the great Barranca del Cobre, far off the tourist beat. Rather than war, the incentive for physical development among the peace-loving Tarahumara doubtless lies in the stark reality of sustaining existence in some of the most rugged and craggy wilderness of North America. Probably even more of an inducement, however, is the fact that running is the principal sport. Being fleet of foot is at the same time his livelihood, his recreation, and his criterion of success.

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Received for publication April 20, 1970.
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*Presented in part at the Fiftieth Annual Session of the American College of Physicians, Chicago, Ill., April 23, 1969.

This pilot study of the incredible degrees of physical stamina habitually developed by the Tarahumara Indians is offered on the precept that often valuable clues can be gleaned from observations of extremes—of use of medications (e.g., determination of the "minimum lethal dose") or alcohol, of stresses, aggression, slothfulness, or dietary excesses, as of many physiologic variables. In the same way, we might look for the limiting factors in human physical endurance, a sort of M.L.D. of exertion, and for its ultimate effects on the heart which must inevitably sustain the brunt of that exertion.

The Tarahumara and their feats

Little is known of the origins of the Tarahumara, though they are classed by anthropologists as one of the few Uto-Aztecan tribes to survive as functioning aboriginal cultures, largely sequestered from civilization and retaining many of their prehistoric modes of life. Presumably they were found there by the early Spanish settlers who came into the Sierra Madre Occidentale Mountains of Mexico in the sixteenth century. Advancing civilization has rolled back their lands which now are confined largely to the southern third of the state of Chihuahua and range in topography from tropical gorges as much as a mile deep to the vast rocky and wooded highlands, little of which is tillable. Further isolated by their language, which is unwritten and unique, the Tarahumara are a shy people who still mix little with the more familiar Mexican cultures and continue to subsist, dress, eat, and play much as they did as long ago, perhaps, as the heyday of the Spartans.

Staple of their diet is pinole, a highly concentrated food made from finely ground, toasted corn, eaten in many forms, liquid and solid.[1-3] Even their mainstay intoxicant, tesguina, is a fermentation product of corn sprouts. Various preparations of beans furnish a large part of the protein in the diet, while squash and assorted greens supply much of the bulk. In times of corn shortage, wheat is used extensively and, in very lean months, numerous wild plants and roots are resorted to, including cactus. Several fruits are cultivated, as is strong tobacco which the Tarahumara smoke in cornhusk cigarettes.[2] Relatively little meat is consumed and seldom is livestock slaughtered for food except on occasions of fiestas and tesguinadas (which evidently are not infrequent). Undernutrition and malnutrition are known to be widespread.

Unusual stamina has characterized the Tarahumara from the earliest recorded descriptions of the tribe. As would be expected, anthropologists long preceded physicians in investigative sorties into this remote area. Amazing physical feats are described by the explorer, Lumholtz,[1] who lived among these people in the 1890's and provided a detailed account not only of their foot races but of their entire culture. A more modern compilation of virtually all the anthropological literature to date, as well as their own first-hand observations of these Indians, is the excellent book by Bennett and Zingg[2] which likewise documents the rigorous Tarahumara existence and such feats as what must certainly be the most primitive method of hunting a deer, that of running after him relentlessly for a couple of days until the animal drops from exhaustion. Similarly the wild turkey is stalked simply by pursuing him until he can no longer rise from the ground in flight. And other game ranging in size from birds and mice up to coyotes are commonly felled by rocks which the hungry hunters learn to throw with uncanny accuracy.[2] Ingeniously, these Indians have learned to harvest fish by introducing into the water upstream drugs* which stupefy the fish, rendering them literally "doped to the gills" yet still fit for the Tarahumara table. A veritable pharmacology of fishing and of ceremonial drugs, data on their diet, along with an exhaustive bibliography dating back to Jesuit records of 1645, are included in the monograph of Pennington.[3]

In a region with no roads and many paths, some of them negotiated more readily on foot than by burro, running affords a very real utility as well as sport. Tarahumara are said to compete effectively with mules as a means of transportation because they go faster and further in a day, carrying heavy loads of mining timbers and lumber for hours at a time up and down steep mountain slopes.[2] With their unmistakable

*Prepared chiefly, according to Pennington,[3] from *Cacalia decomposita, Cracca talpa, Casimiroa edulis,* and *C. patota.*

native attire, they are a familiar sight in the city of Chihuahua, capitol of their state, some of them traveling afoot hundreds of miles en route.

But the Tarahumara's high level of physical conditioning is nowhere as evident as in his "kickball" races which seem to constitute almost the *raison d'etre* of a harsh and precarious existence. Documentation of these marathons is abundant.[1-4] The sport consists of running continuously, day and night, along paths and trails over mountainous terrain, kicking (actually flicking with the dorsum of the foot) a ball the size of a tennis ball carved from wood with a machete knife. Races covering linear distances of 75 miles or so are common, while major inter-pueblo races go on for as long as two days and two nights covering, in a monitored number of laps over a marked course, as much as 150 miles and more. If a runner drops out for pinole or for "curing" of his legs or other ministrations by his medicine man, he must make up the lost distance upon rejoining his team before he is again eligible to kick the ball. Betting is the order of the day on these festive occasions; clothes, livestock, jewelry, knives, blankets, even land are wagered in days or weeks of ritualistic preparations by villagers, as many as several hundred of whom then join in the competition by running along a lap or two, spurring on their teams or trying to confound their opponents, carrying torches at night or supplying small rations of food and fluids to the contestants as they pass by. A recent race near Sisoguichi, witnessed by the local padre, Father Llaguno, covered a measured distance of 161 miles, only two of the twelve entrants finishing. Interestingly, a traditional prize of victory is said to be a special popularity with the women (although how much of a reward that would actually prove to be for a man who had been running for two days and a night is questionable, to say the least!). Therein may lie some element of natural selection.

Certainly such fantastic feats of endurance can be achieved only after long, arduous, and perhaps unprecedented physical conditioning. The Tarahumara begins running almost as soon as he learns to walk.[2] Groups of small children are frequently seen racing along trails and over hills pursuing their kickballs. More or less practice races of fifty miles or so are a favorite pastime among members of the same community, and even a solo traveler through the countryside may be seen jogging along behind his kickball which he learns to propel with unerring control. Women of the tribe have their own type of race, employing small hoops which they hurl through the air with sticks. Their contests extend over shorter distances, although they also last through the night and entail much wagering.[1,2] It should be emphasized that the Tarahumara excels not in speed but in endurance. His gait is a rhythmic, swinging one (Fig. 1) that bespeaks an economy of effort; his pace is moderate but unrelenting.

Physical and physiologic observations

Detailed investigation of runners in action poses certain problems. One is that the really big races are unscheduled and unpredictable as to time and place. More important to the Tarahumara, a kickball race is serious business, for not only does it rate him as a man but it entails betting what to him may be high stakes. Understandably he does not want to be encumbered by monitoring devices or detained by unfamiliar examination procedures. Then too, the competition (as well as practically all spheres of Tarahumara life) is fraught with much mysticism and superstition which can impart fearful significance to even commonplace occurrences. More trusting and tolerant of strange gadgetry, such as stethoscopes and electrocardiographs, are those Indians who have lived in or around one of the mission settlements established by the Jesuits two and three centuries ago. They are undoubtedly less primitive than their more isolated tribesmen whose lives have not been touched by the Caucasian influence of the missions or lumber camps, but first-hand observation attests to their quaint native ways and their marvelous feats of physical endurance. Headquarters for these studies was the mission at Sisoguichi, lying 100 miles southwest of the capitol city of Chihuahua, while the chest x-rays were made on other Tarahumara

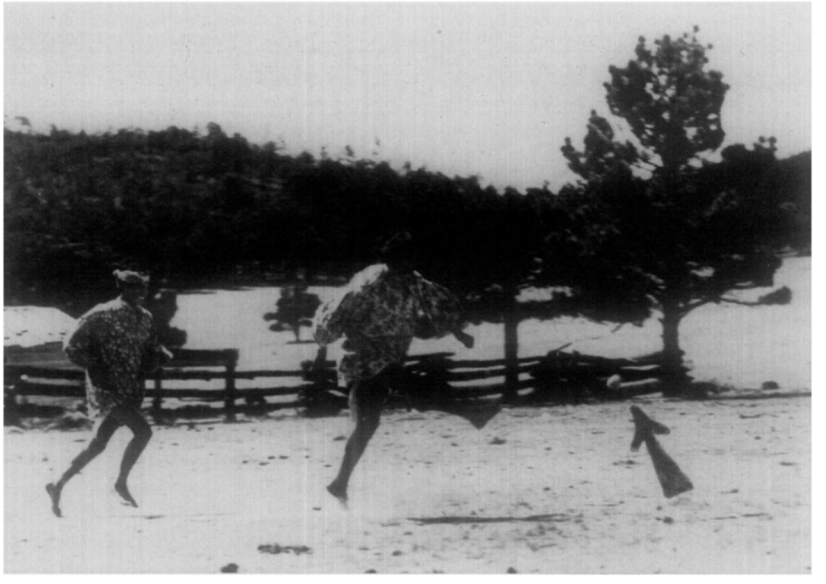


Fig. *1*. Two Tarahumara running barefoot through a meadow near the Mission with the kickball in air (arrow). Native men are clad in a loincloth attire which is ideally suited to a long swinging stride. Women, on the other hand, manage somehow to run dozens of miles in almost ankle-length, colorful skirts, even with a papoose on the back.

runners at a small mission hospital in Norogachi, about fifty miles to the south of that, not far from the spectacular Barranca del Cobre.

For purposes of these studies, a Tarahumara kickball race was staged (at the behest of their beloved padre, Father Llaguno, and with the substitution of a few pesos and articles of clothing for the native wagers) from Sisoguichi to Panalache and return. The measured distance of this course was 23 km. each way, or a total of 28.6 miles. This mileage, it should be noted, is that of the over-all course distance, whereas the actual distance traveled by the runners in their devious pursuit of the balls, up and down over rugged terrain at altitudes of 7,000 to 8,000 ft. above sea level, was lengthened by an appreciable but unmeasurable amount. Eight male Indian runners ranging in age from 18 to 48 yr. competed in two teams of four each, the winners covering this course in four hours fifty-five minutes running time, the others crossing the finish line approximately fifteen minutes later. Calculated average speed of the winning team was 5.81 miles per hour. Since no allowance was made for time lost or digressions along the way looking for lost balls or for the requirement of having pieces of paper signed by the Mayor of Panalache at the turnaround point on the course, their actual running speed would average over six miles per hour* for the race. Observations of pulse rate and blood pressure were made before, during (at a three-quarter point which we reached by jeep travel) and at the end of the race. All runners finished easily what was obviously regarded by them as little more than child's play.

Summarizing the data, each contestant in the race lost about five pounds in weight, attributable to dehydration at that ambient temperature of approximately 65° F. More surprising was the marked decrease in diastolic blood pressure which was a universal finding. Whereas all the runners had normal blood pressures at the beginning, two of them (ages 22 and 32) showed diastolic readings of zero during and immediately at the end of the race, rising within a few minutes to 60 to 80 mm. Hg. Others had diastolic levels (by the usual cuff method) ranging from 40 down to 8 mm. Hg. All runners, checked both at the three-quarter point and at the end of the

*Again I should emphasize that this is not a *fast* race on standards of, eg., the Boston Marathon. It is the *endurance* of the Tarahumara runners that is unique, demonstrated in races over courses several times this distance.

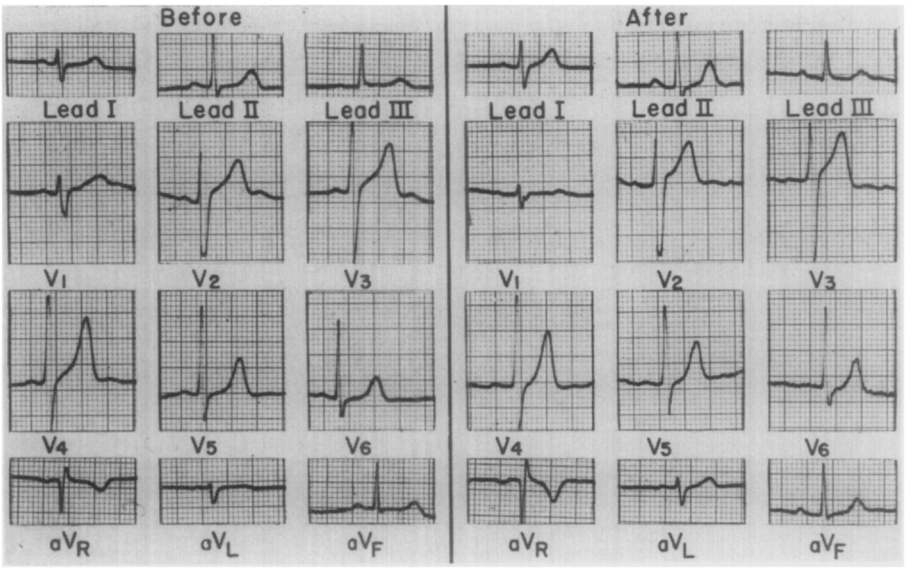


Fig. *2*. Electrocardiograms before and immediately after the 28 mile race, recorded (supine) on 23-year-old Severiano Salido, one of the winning team.

race, showed declines of systolic as well as diastolic pressures, the highest levels being 122/80 and the average approximately 110/70.

Pulse rates were determined, as were all the blood pressures, within a minute or two and with the subjects standing. The maximum rate recorded was 158 beats per minute, that in the latter half of the race and on the 23-year-old runner whose electrocardiogram is illustrated in Fig. 2. (ECG's of two of the other contestants are shown in Fig. 3, along with that of a thoroughly acculturated "control.") Rates on all the others were in the 120 to 150 range counted immediately after crossing the finish line. True resting pulse rates, as with the blood pressures, were not obtainable in the aura of excitement with anticipation of the contest and the unfamiliar medical preparations which we introduced but they ranged here from 62 to 90 standing. (Subsequent counts on four adult runners checked supine and without the competitive stimulus of a race disclosed rates of 56 to 60.) All these observations are in line with those of Balke and Snow[4] who, in a similarly staged Tarahumara race, also found increases in serum cholesterol levels of about 25 per cent above the pre-race values which, incidentally, were generally below

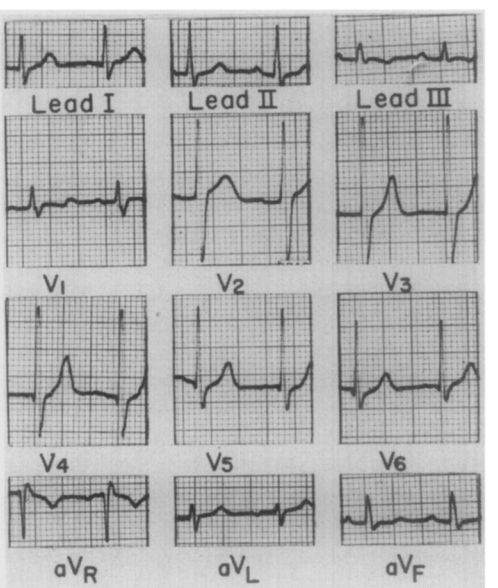


Fig. *3A*. Electrocardiogram (ECG) on 22-year-old Francisco Ruiz taken at the end of the race.

100 mg. per 100 c.c. The mean hemoglobin levels (17.2 Gm.) and hematocrits (51) which they reported are explainable on the mile and one-half high elevation of this area of Mexico.

B

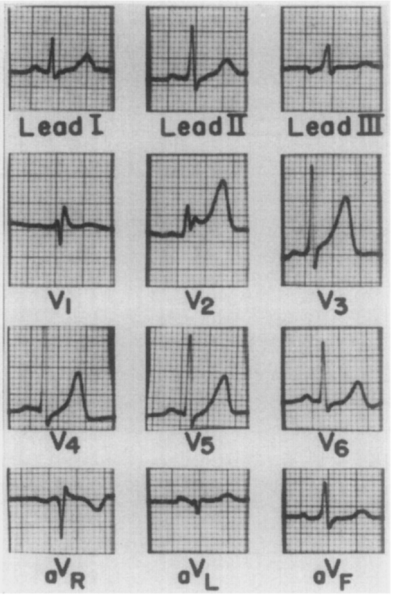
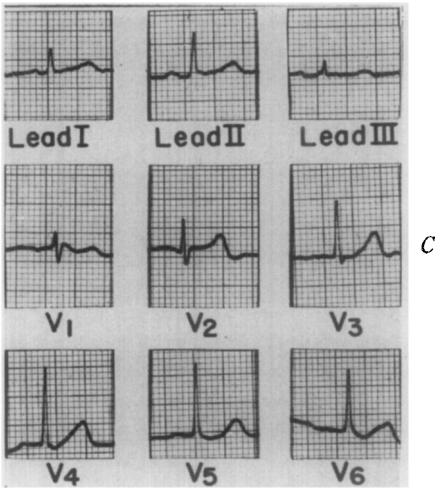


Fig. *3B*. ECG on 48-year-old Louis Diaz recorded 15 min. after the race. It does not differ significantly from that of the "control" subject (*3,C*).



C

Fig. *3C*. ECG on 38-year-old Nikolas, the "control" Tarahumara, who spent his years in the less strenuous life of the Mission.

Certain physical characteristics of these runners are worthy of note. Those competing in the Sisoguichi-Panalache race were conspicuously thin and relatively short as compared with United States population standards. In height they measured from 5 ft. 2 in. to 5 ft. 6 in. and the average weight was 120 lb. (range 114 to 135 lb.). An idea of the leanness of these people is conveyed in the measurements which we made of the abdominal panniculus by calipers: in all eight of our runners a single fold of fat pad was less than one centimeter, most of them only 5 to 7 mm. (The two United States examiners must blushingly admit to measurements nearly ten times as great.) As a Tarahumara control, our houseboy and jeep driver, Nikolas, who had been born and raised amid the comparative comforts of the Mission, had an abdominal panniculus of 3.5 cm., was 5 ft. 4 in. in height, weighed 134 lb., had a resting blood pressure of 95/60, pulse 72, and the normal electrocardiogram shown in Fig. 3,*C*.

All eight of the contestants in the race were examined carefully and none were found on physical examination to have evidence of cardiac enlargement, unusual accentuation or splitting of the second heart sound, or suspicious murmurs. Their musculature was impressively firm. Almost unbelievable is the pulmonary performance of these runners who, after running competitively for hours, cross the finish line and stand quietly without panting while one examines them, seemingly unperturbed by the effort. At the conclusion they show a calmness not evident in the anticipation of the race.

Discussion

What then are the limiting factors at the extreme end of the scale of human physical endurance? Really definitive physiologic data are exceedingly difficult to come by in these isolated, clannish people who speak an unwritten language of their own and are not even counted on the country's census with any degree of accuracy. Meaningful medical records or just simple vital statistics are virtually unknown in the Tarahumara, for relatively few of them are ever seen by a nurse, fewer yet by a physician. Most still live and die much in their ancient patterns which are not readily amenable to scientific scrutiny. Thus an investigator of their ways is left with the limited literature available, mostly anthropological, with whatever first-hand observations of these people he can muster, and with the few interpretive bridges to their culture, such as Father Llaguno and acculturated Indians

like Nikolas. Hopefully we may derive more knowledge of this unique tribe before their culture is too diluted or swallowed up altogether in the encroaching civilization which virtually surrounds them.

One physical limitation that we would expect is conspicuously absent in all accounts. That is a limitation in cardiac capacity. Definitely the heart is not the weakest link in the chain of Tarahumara stamina. At least in this primitive setting, with a people acclimated for generations to an arduous existence and conditioned since childhood to physical exploits that constitute both their livelihood and their sport, cardiac symptoms as we know them are not the end point of endurance. Nor, it would appear, are any indications of respiratory distress. Indeed, it may well be that more runners drop out of the contest because of superstition and fear than because of physical limitations. Perhaps the Tarahumara instinctively knows what Shephard[5] has calculated in physiological terms, namely, that "the intensity of stress imposed upon the heart by an anxiety reaction may exceed that incurred during maximum exercise" and he exploits that to advantage by intimidating or frightening his opponents. Nevertheless sheer fatigue must surely take a toll, though it is stoutly denied by proud contestants.

One would like to have precise measurements of many physiologic responses incident to these marathons. What happens to blood volume, to electrolytes, to carbohydrate and lipid stores during a race of 100 miles? Does the conditioned Tarahumara have a different sort of metabolic economy which enables him to better tolerate what must be an enormous oxygen debt incurred at altitudes a mile and a half above sea level? Energy expenditure of these runners, using a rate of 11.6 Kcal. per minute (equivalent to an oxygen consumption of 2.4 L. per minute which would be perhaps a conservative figure for an average pace of 6 miles per hour over such rough and hilly terrain) would calculate out at more than 11,000 Kcal. for a 100 mile race. A comparable estimate was arrived at by Balke and Snow[4] who pointed out that this exceeds the generally accepted limit of energy that can be expended by the most strenuous voluntary activity over a period of 24 hr. So if these estimates are nearly correct, we need to revise our physiological concepts of maximum–or potential–work tolerance in the human.

Obviously more questions than answers are raised by these observations. Quite likely there may be arrhythmias, repolarization changes, injury currents, or other electrocardiographic abnormalities present during and not immediately after the exertion. More significant than their qualitative presence, however, would be the changes evoked by stress if, as contended, transitory disturbances of rhythm and conduction are almost universally present during normal activity in middle-aged men of our own population.[7] Certainly, continuous monitoring throughout a twenty-four or forty-eight hour marathon would be of prime interest, as would a gastrocnemius biopsy thereafter. One would like to know what happens to renal function as a result of this prolonged ordeal. What are the effects on visceral and peripheral circulation, on cardiac output, cerebral blood flow, oxygen transport, and metabolic end products? With the recent controversy about a possible role of physical conditioning in atherogenesis and in development of coronary collateral circulation, autopsy examination of hearts and arteries of these super-athletes would provide more direct evidence than any clinical data. However, in a situation where the limited and rudimentary medical care that is available is provided mainly by nurses in the missions, such investigations must await the most urgent necessities of the living.

Recently additional trips to Mexico were devoted mainly to gathering information relating to symptoms, physical complications, and sequelae of the races. Extensive interviews were carried out with several Tarahumara runners through Father Llaguno as interpreter. Physicians at the Medical School of the University in Chihuahua and in the environs of that city were consulted. Doubtless, information gleaned in this way may reflect a bit of subjective coloring but, nevertheless, certain points emerge with general agreement.

No instance could be recalled of a runner ever dropping out of a race because of pain in the chest or shortness of breath. Exhaustion yes, and sometimes abdominal dis-

comfort, but never any pain in the chest, arms, shoulders, or neck. Nor could anyone recall over the years a specific instance of a contestant dying during a race. However, rare cases of death after unusually long races were acknowledged, with time intervals presumably of no more than a few days.

A common type of complaint had to do with disturbances in urination. Apparently runners become especially concerned over any scanty urination or anuria occurring either during or after long races. It is understandable that dehydration accompanying the exertion would cause an oliguria, but evidently a reduction or absence of urine output may occasionally persist for several days in some of the more discomforted participants. One wonders whether acute renal failure might be a reversible consequence in these circumstances, resulting perhaps from hemoglobinuria or myoglobinuria. Usually though the contestants, after an especially long marathon, will indulge themselves in much rest and food for a week or so, then rise to race another day.

Unquestionably, the main physical factor which limits endurance in Tarahumara races is that of pains in the legs. From all the accounts, these are predominantly muscle rather than joint pains and they are of such import to the runners that literally days are spent before and after major events in ritualistic bathing or "curing" of the legs, anointing them with various nostrums such as herbs and goat grease.[1] Despite all this, apparently it is skeletal muscle which gives rise to most of the symptoms associated with the longer races and claims the greatest number of physical casualties. Really outstanding contenders are said to become so imbued with the spirit of the competition that they are insensitive to all pain until later. Losers, on the other hand, fall by the wayside either because they are bewitched by one of the many bizarre (and ostensibly potent) superstitions* of racing, or because their threshold for discomfort or fatigue is lower. Runners made of sterner stuff go on to victory and the rewards of their wagers and their laurels.

*For example, one ingenious "hex" perpetrated by the shaman (medicine man) of a team is to exhume from a burial cave a Tarahumara tibia or femur, grind it up and sprinkle the bone dust over a part of the course which his own runners are then cautioned to avoid. The opposing team, unaware of these machinations, inadvertently steps into this area of contamination where evil spirits from the dead are reputed to reach out and seize the legs of the hapless runners.[2]

Several of the more dramatic "end points" of physical exertion described in the literature did not seem to hold for the Tarahumara. No history could be elicited which would suggest syncope as a complication of their races. Neither rupture of a previously unsuspected aneurysm nor coronary insufficiency, cited as the two commonest causes of death in endurance events,[5] could be substantiated in the lore or accounts of Tarahumara life. Special inquiry was made along the lines of sudden incapacitation or death attributable to an arrhythmia, infarction, or pulmonary edema with negative results. If there is a thermoregulatory problem—for deep body temperatures are known to rise as high as 105.8° F. (41° C.) in protracted exertion[5]—these Indians are unaware of it, as we were. Evidently the Tarahumara, who in a real sense live by their muscles, achieve a sort of "special dispensation" from some of these human limitations known to us.

It has been postulated that during very strenuous exertion the increase of coronary blood flow may give a greater pressure drop across any plaques in the coronary arterial tree and thus predispose to hemorrhage into the plaques. Also increased levels of circulating catecholamines, as well as "patchy hypoxia" of the myocardium have been suggested as causes of ventricular fibrillation and sudden death during maximal stress.[5] One might speculate that these complications are more often the result of unaccustomed exertion, or at least excesses to which the performer is not sufficiently acclimated by training.

A long-range limitation traditionally ascribed to athletic pursuits is cardiac enlargement. Particularly in the older medical literature, there are numerous references (but little evidence) to hypertrophy of the "athlete's heart" with the implication of premature death from overwork of that organ. If that were the case, surely the virtually lifelong and extreme training of the Tarahumara should give rise to conspicuous cardiac enlargement. Yet examinations of the runners at Sisoguichi disclosed no evidence of cardiac abnormality,

either physical or electrocardiographic. Chest x-rays made at Norogachi on eight other Tarahumara adults, most of them middle-aged, all showed heart shadows within normal limits as to size.* Four of those films are reproduced in Fig. 4. Measurements of ventricular wall thickness would of course be more conclusive, but it appears from all our observations that the hearts of these Indians must respond to their increased work load in ways other than enlargement.

Perhaps a little speculation would not be out of order if put forth as such. First, how much of the Tarahumara endurance is attributable to survival of the fittest throughout many generations of adjustment to a rigorous existence, high infant mortality and natural selection? Several attempts have been made to compare them with athletes of other countries, as in the 1928 Olympics, but the Tarahumara are said not to perform at their utmost when brought down from their high country and bewildered by the complexities of our more regimented athletic competition. Evidently few of them elect to mix with other cultures but an occasional dropout can be found, like Nikolas, whose upbringing has been more sheltered and sedentary and who, like most of us, would be left in the dust of the first lap of the race. Genes alone cannot account for their stamina, and diet is hardly a plausible explanation. Surely the major determinant must be that of sheer physical conditioning, beginning in early childhood, dictated largely by necessity but carried to a degree unprecedented in modern times by competition and custom. At least a partial insight into the mechanism may be found in the antithesis of conditioning; just as loss of muscle strength can be shown to proceed at a rate of approximately 3 per cent per day during prolonged bed rest,[6] bearing out a sort of immutable biologic law that *we lose that which we do not use*, so also the converse must be true. That is, by intensive training, started early in life and progressively increased throughout the developmental years, a normal person can greatly extend the functional capacity of his muscles and doubtless his entire cardiovascular system in much the same way that the blind man develops his senses of touch and hearing, or the native diver adjusts to holding his breath two minutes underwater. True excellence and distinction in feats of memorization, of musical performance, of writing or juggling or running are seldom attained without extraordinary persistence and practice. Physically, the Tarahumara exemplifies that to the nth degree. To him it is not a task of exercise for the sake of exercise, as with so many of our urban joggers. For he has a "gimmick"—a wooden ball. And that makes of an otherwise drab existence real fun.

*All x-rays were made at the two-meter distance conventional for the German equipment employed. Cardio-thoracic ratios were: 11.7 to 26.0, 11.0 to 24.2, 14.0 to 30.0, 12.0 to 29.2, 14.0 to 32.0, 12.7 to 28.5, 13.5 to 29.7, 12.7 to 28.0 cm. Films of all eight subjects were reviewed by a staff (University of Oklahoma) radiologist and judged to show heart shadows normal in both size and contour.

Conclusions

1. Most remarkable is the simple fact that the human cardiovascular system can be conditioned to withstand the extremes of endurance demonstrated in Tarahumara races of 100 miles and more. Probably not since the days of the ancient Spartans has a people achieved such a high state of physical conditioning.

2. Apparently the limiting somatic factor in these marathons is skeletal rather than cardiac muscle. End-point symptoms are predominantly cramps in the legs, often accompanied by various urinary complaints. Deaths from cardiac or circulatory complications are unknown.

3. Contrary to traditional belief, no enlargement in these "athlete's hearts" was evident on physical examination or x-ray. Also no abnormality was seen in electrocardiograms either before or immediately after a 28 mile race. Why this virtually lifelong increase in work load on the heart does not cause appreciable cardiac enlargement, whereas diseases such as hypertension and aortic stenosis do, is not clear, nor are the mechanisms by which these runners can cope with inevitably large oxygen debts at altitudes of a mile and a half above sea level. One clue to their adaptive mechanisms may lie in the observed decrease rather than increase in systolic and especially in diastolic blood

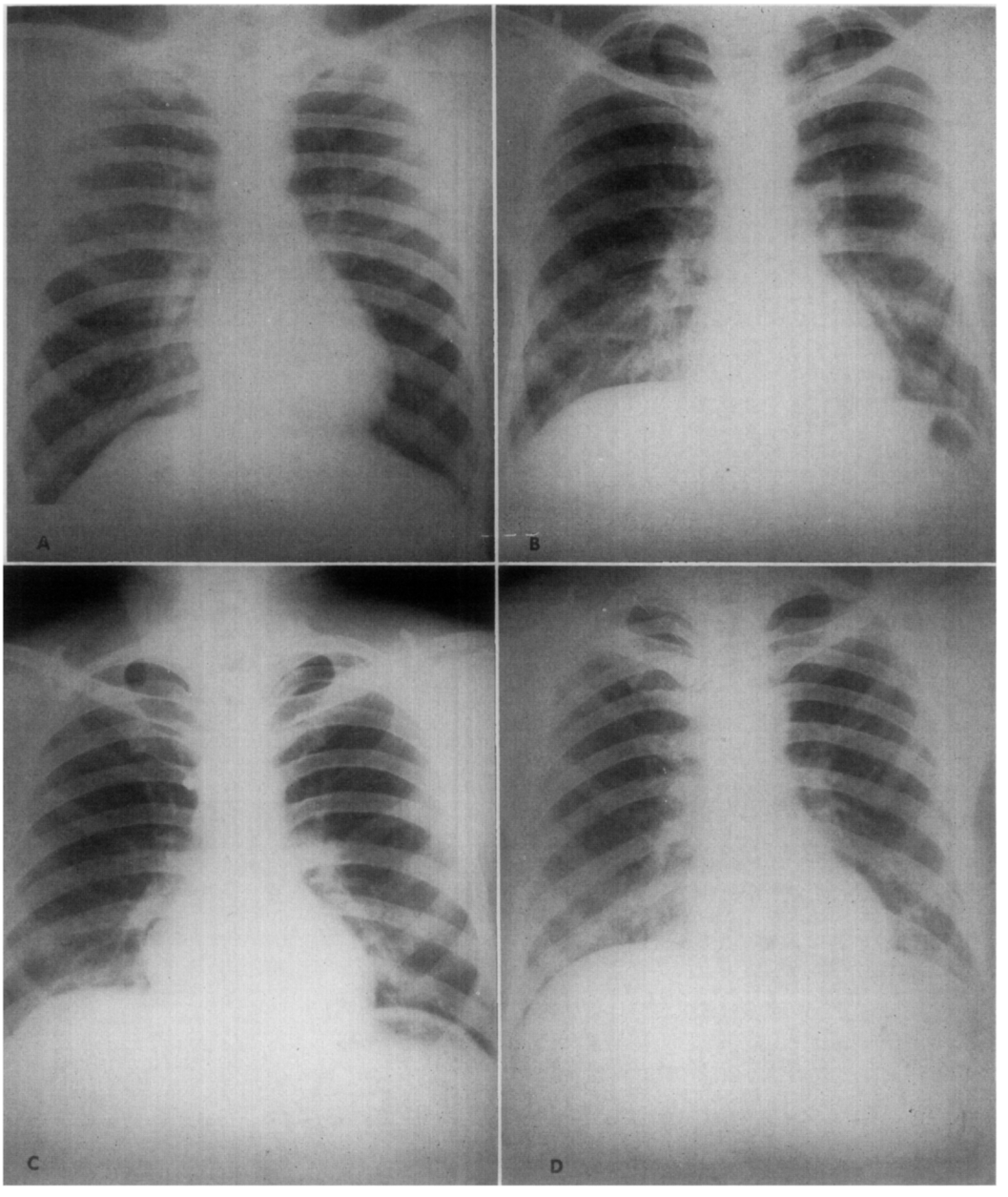


Fig. *4, A, B, C,* and *D.* Chest x-rays on four unselected Tarahumara runners, all men, ages 22 yr. (*A*), 40 yr. (*B*), 45 yr. (*C*), and 48 yr. (*D*). All views are posteroanterior, made on rather antiquated European equipment, but at the standard 2 meter tube-to-film distance.

pressure levels during and immediately after prolonged exertion.

4. The phenomenal feats of physical endurance of these primitive Indian runners afford convincing evidence that most of us, brought up in our sedentary, comfortable civilization of today, actually develop and use only a fraction of our potential cardiac reserve.

The author owes a great debt of gratitude to the Reverend José A. Llaguno, S. J., a scholar with two masters degrees and a Ph.D., who has devoted his life, as have generations of Jesuit priests before him, to the Tarahumara Indians of Mexico. He probably

knows more about these people and their ways than any living Caucasian. "The Padre" is a warm friend and an accomplished fellow pilot without whose collaboration these studies could not have been accomplished.

Special acknowledgment is due also to Dr. John Steelquist of San Diego, Calif., who has had a long-time interest in the Mission at Sisoguichi and opened many doors there by way of introductions. Also Brigadier General Franklyn S. Henley, USAF retired, assisted in the blood pressure and pulse rate determinations. Our ECG's were recorded on a portable, nine-pound battery-operated electrocardiograph, the "Cardioview," manufactured in England by Honeywell, Inc. This convenient little instrument (which currently is not marketed in the United States) was loaned for these studies by Dr. D. C. Sutfin of Honeywell. The chest x-rays were made by nurses of the Jesuit Mission in Norogachi, Chihuahua, and were interpreted by Dr. William A. Weidner, Professor of Radiology at the University of Oklahoma.

Especially we are indebted to our amazing subjects, the Tarahumara. For it is they who teach us something of our own potential by providing an impressive precedent of physical conditioning—a goal that is easily neglected and lost sight of in our sedentary civilization.

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