swimming the butterfly stroke. These patients were all diagnosed as having Scheuermann's kyphosis. The authors were not certain whether the forceful contraction of the chest and abdominal musculature during the power phase of the butterfly stroke caused the vertebral abnormalities or merely were an aggravating factor. Two of three experienced dramatic relief by stopping the butterfly stroke. Such patients should be encouraged to continue with their swimming program but should confine their swimming to the backstroke and freestyle.

SUMMARY

The practitioner need not be an expert in swimming but should understand the rudiments of the stroke and training techniques such patients are subjected to. This will aid in proper identification and analysis of the problem. The solution may require the resources of physician, therapist, coach, and parent as well as swimmer.

REFERENCES


Scoliosis in Swimmers

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Children who become interested in swimming and begin to participate seriously often do so at very early ages, sometimes as young as six or seven. This early involvement very often exposes them to types of stress that can affect the growth and development of their maturing musculoskeletal systems in an adverse way, producing a disruption of the normal growth pattern. The most potentially serious of these growth disorders is scoliosis or spinal curvature, because it may deform the body and inhibit normal bodily organ function.

FUNCTIONAL AND STRUCTURAL SCOLIOTIC CURVATURE

The vertebral curvature that is defined as scoliosis has been broadly categorized as either structural or functional. The structural curvature category has been described by Willner,44 Hauser,14 and Portillo55 as being a deviation of over 10 degrees, accompanied by rotation. This definition specifies the inclusion of bone and ligament malfunction as a criterion for structural torsion associated with a lateral curvature. Functional scoliosis has been referred to by Keim54 as a “mild” form of the vertebral disorder, because it is not necessary to correct the condition by an external device, but rather it can be corrected by side bending. Arkin further noted that the functional or mild curve may in some cases be an initiating cause of the more severe structural curvature, but it is not a fault which correction is possible without surgery.

Tachdjian noted that functional scoliosis generally has a single long thoracolumbar curve with a predominately left convexity. His work indicates functional scoliosis produces little rotation of the vertebral body with accompanying rib deformity, which is the serious secondary complication of idiopathic scoliosis. One of the characteristics of functional scoliosis is that the curve will disappear during recumbency and suspension, and the spine bends equally well to both sides on lateral flexion of the trunk, with
rotation to both sides being equal. According to Tachdjian, the majority of functional scoliosis cases are attributable to compensatory lower limb growth, or compensatory pelvic tilt adjustments affecting the lumbosacral junction. Some degree of functional scoliosis is a common occurrence with poor posture, but this entity is of little clinical importance and ordinarily requires no treatment.

INCIDENCE OF SCOLIOSIS

The incidence of idiopathic structural scoliosis has been normally low among the general population, but is notably higher among adolescents. In a 1955 survey of 50,000 adolescents in the general population, Shands and Eisberg found 1.9 per cent or approximately 1,000 subjects to have scoliosis. Avikainen and Vaherto in 1983 reported scoliosis to be present in 3 to 16 per cent of the population, depending on the degree of curvature that had been chosen as the limit of scoliosis, and on the age of the subject. These percentages are similar to the findings of Willner, who in 1984 reported 0.35 to 13 per cent as the incidence of structural scoliosis. Eckerson and Axelgaard in 1984 also reported that idiopathic scoliosis, with a lateral curvature of unknown etiology, comprises 75 to 80 per cent of all scoliosis in the United States.

Studies focusing on the incidence among men and women include the work of Shands and Eisberg, which showed a predominance among women; the incidence of scoliosis may be five times as great as that found in like male populations. Avikainen and Vaherto report in all cases of scoliosis requiring treatment, 90 per cent are women, but mild scoliosis is observed to be nearly as frequent in boys as in girls. Other investigations by Wynne-Davies and Fisher and DeGeorge surveyed familial incidence of scoliosis and the relationship to mothers' age. These studies showed a significantly greater than expected number of scoliotic curves among the offspring of mothers who were considered to be older. In additional investigations, Yarom, Wolf, and Robin indicated that growth and sex hormones and scoliotic onset later in life may be decisive factors in the propagation of the deformity.

Further work on the incidence of scoliosis reported by Kuprian, Ork, and Meissner postulated that Jenschura found the average frequency of idiopathic scoliosis in athletes to be 2 per cent. Krahl and Steinbruck, in examining 571 top athletes in 1974–1977, found a 33.5 per cent incidence of functional scoliosis and a 1.6 per cent incidence of idiopathic scoliosis, similar to the incidence noted by Shands and Eisberg. Kuprian, Ork, and Meissner postulated that the high incidence of functional scoliosis among athletes is notable among those participating in sports that develop extreme torque in repetitive serving, throwing, and volleying motions, such as archers, javelin throwers, pole vaulters, and table tennis players.

The clinically observed scoliosis in swimmers does present the aquatic sports physician and therapist with a potentially interesting investigation as to etiology and incidence. Owing to the great number of adolescents engaged in competitive swimming programs each year, a preliminary study was conducted to ascertain the incidence of scoliosis among this group. In August of 1983, at the Junior Olympic Swimming Championships East, held at the Indiana University Natatorium, Indianapolis, 336 of 1200 competitors underwent evaluative screening for scoliosis. The procedure was patterned after the protocol of Dendy, Chase, and Determann. This screening procedure included observations with the athlete in the standing erect position, and then in the forward bending position. In the standing erect position, observations were made for asymmetries of the lateral contours of the trunk (Fig. 1), shoulders, scapulae, and the lateral deviation of the spinal processes (Fig. 2). In the forward bending position, the observed rib hump asymmetry was considered to be the positive clinical finding for structural idiopathic scoliosis (Fig. 3).

Of the 336 athletes who participated, 193 females and 173 males, 6.9 per cent were found to have mild functional scoliosis. The 6.9 per cent figure represents an incidence that is three and one half times the normal incidence, and is well above the 1.9 per cent figure in other studies, whereas the 16 per cent is similar to the high figures of Avikainen and Vaherto and of Willner, yet below the 33.5 per cent figure of Krahl and Steinbruck.

The screening investigation at the Junior Olympic Swimming Championships East, in which 16 per cent were noted to have mild functional curvatures, did produce a unique statistic. In this study the 16 per cent figure included a 100 per cent occurrence of lateral curvature to the hand-
dominant side of the body. This supports the muscular imbalance according to Hauser, and the dominant arm strength as noted by Yeater et al. as possible contributors to these particular investigations. It is obvious that the incidence in this small population is of interest to the swimming community, owing to the fact that the event at which the screening clinic was conducted is noted to be a select event. Competitors were entered based on their being capable of swimming at an acceptable level prior to entry, thus placing this population in an elite category, similar to those athletes studied by Krahl and Steinbruck.

**INTRINSIC EFFECTS OF SWIMMING**

It has been stated by Magel and McArdle that the propelling force in swimming depends on muscular strength and effective stroke mechanics. Swimming speed increases depend in part on buoyancy, the hydrodynamics of correct stroke technique, and wave-making resistance. The propulsive force must equal water resistance, and swimming velocity will result from the relative equilibrium found between force and resistance. Piette and Clarys electromyographic data revealed the muscles most responsible for the propulsion of the competitive swimmer were the latissimus dorsi, rectus abdominis, gluteus maximus, biceps brachii, and pectoralis. Their investigation revealed the latissimus dorsi, rectus abdominis, and gluteus maximus were the most active muscles during the freestyle stroke. Results of the study showed that competitive swimmers tested had significantly greater propulsion on electromyography than a like number of noncompetitive swimmers. This study also found the muscular efforts of competitive swimmers were significant for the level of activity in the back, abdominals, and muscles of the pelvic girdle. In succeeding electromyographic studies, Clarys again investigated the latissimus dorsi and rectus abdominis muscles and the results confirmed these to be the most active in duration and strength during the freestyle of all the muscles investigated.

Propulsive efficiency studies by Svec examining the freestyle stroke note the first state of the arm motion produces a pressure curve that is very close to linear from the point of hand entry and pull (Fig. 4A) through to the initial inward scull (Fig. 4B). The second phase of the stroke, in which pressure curves are greatest, occurs during the last stage of propulsion, in which the hand passes mid chest in the push (Fig. 4C) and finishes in an outward scull phase (Fig. 4D). High pressure during the propulsive phase of freestyle is almost always present with a duration that is considered to be variable. Yeater et al. in examining the force traces for the crawl stroke, observed that many individuals consistently produced greater peak force with one arm or the other during all phases of propulsion. Quantification of the stroke asymmetry in this study was performed by dividing the right-left differences in peak force by mean peak force, and no appreciable correlation was found between this variable, as well as mean tether force, and competitive velocity.

In another study on the analysis of swimming motions, Gallenstein and Huston found there are dips in the output velocity for all strokes, owing to upper extremity work. Freestyle kicking was noted to produce relatively small changes in the overall freestyle propulsion, and therefore the effort of the upper extremities was interpreted as being relatively unaffected by the efforts of the lower extremities.

Morphologic studies by Sahgal et al., Yarom, Wolf, and Robin, and Tachdjian show there are generalized myopathic changes in the paraspinal and gluteus muscles of individuals with idiopathic scoliosis. The structural
skeletal changes would then be expected to be accompanied by secondary adaptation of the supporting vertebral soft tissues. The change in soft tissue function is characterized by Tachdjian and Hauser as being atrophy, weakness, and fibrosis on the convex side of the spine, and thickening and contractions on the concave side. Of all muscle types tested, there was significant glycogen content, and the mitochondria were found to be significantly higher on the convex side and in the gluteus, but not on the concave side of the apex, where significantly high Z-band values were found.

The histographic work by Yaron, Wolf, and Robin dealt with analysis of the deltoids and the trapezius and quadriceps muscles. These authors reported no striking morphologic pathology, but results of interest included fewer type I fibers on the concave side than on the convex side. In several cases, the decline was noticeably marked, and the diameters of the fibers were frequently small or hypotrophic, especially on the concave side.

Fiber distribution and size were shown by Yaron, Wolf, and Robin to be clearly characteristic, with a constant decrease in the deltoids of the concave side for the idiopathic sample. The conclusion that was drawn indicated there may be many factors responsible for the noted changes, including intrinsic and hormonally induced membrane abnormalities.

Muscular adaptation has been the focus of several studies by Maas and Jensen and Bullow. Maas reported the shape of the pectoralis in the concave side for the idiopathic sample. The conclusion that was drawn to be clearly characteristic, with a constant decrease in the deltoids of the convex side. These authors reported no striking morphologic pathology, but results of interest included fewer type I fibers on the concave side than on the convex side. In several cases, the decline was noticeably marked, and the diameters of the fibers were frequently small or hypotrophic, especially on the concave side. In several cases, the decline was noticeably marked, and the diameters of the fibers were frequently small or hypotrophic, especially on the concave side.

Studies of trunk muscular strength in scoliosis are mixed in indicating this area as a sole source of causative stresses. Eckerson and Asclgaard found lateral electrical stimulation of trunk musculature may be effective in reducing the degree of scoliotic curvature in humans, after having artificially induced scoliosis in cats by a similar method. Portillo et al. in research on the trunk strengths of normal and idiopathic scoliotic adolescent girls, reported no significant differences in lateral flexion, flexion, or extension. This latter study was conducted on patients with mild lateral curves, who had to date been untreated by exercise or bracing. The results of this investigation, when compared with biopsy studies showing definite histologic and morphologic changes at either side of the curve, were interpreted as being due to the advanced cases of scoliosis selected for surgical intervention. From this information, the authors suggested the etiology of the scoliotic curve had yet to be determined, and trunk strengths were not a causative factor.

DEVELOPMENT OF SCOLIOTIC CURVATURE

The presence of scoliosis among preadolescent and adolescent swimmers may be indicative of motor development patterns having a direct relationship on the skeletal growth of the vertebrae. Research by Risser...
and Ferguson has shown the spine grows slowly from 7 to 10 years of age, and three to five degrees of curvature may develop each year during that period. The preadolescent age of 10 to 15 years is a period of rapid spinal growth, and curvature increases may develop as quickly as one degree per month. Additional evidence of this age group being a primary population for alteration in vertebral growth has been provided by Zaouasai and James, and Risser, who noted spinal growth in girls stops at an average age of 14½ years and at 16½ years for boys. This would be considered a primary age for obvious scoliotic developments among the many swimmers who have followed prolonged training in order to reach high levels of competition.

It may be assumed that the repetitive exercise motions required in swimming that produce physiologic adaptations, as noted by Lavoie, Taylor, and Montpetit, are also capable of producing muscular adaptation and thus a contracted spinal curve. Tachdjian indicated muscle power of the patient with scoliosis should be examined, in the anterior and lateral abdominals, erector spinae, quadratus lumborum, and thoracic groups. He found this to be required because of the possibility that weakened muscle groups may be an area where unequal upper extremity strength would cause a considerable torsional force, resulting in the scoliotic spine.

SWIMMING AS REHABILITATIVE FOR SCOLIOSIS

The irony of the incidence among swimmers is the recommendation by Kuprian, Ork, and Meissner that swimming is considered the most excellent exercise in the rehabilitation program, because of the need to incorporate a direct breathing technique that prevents thoracic damage. Kuprian, Ork, and Meissner do, however, state all exercises and movements that compress the spine, or require frequent repetition of torsion and sideward motion, should be avoided by the scoliotic patient. These are precisely the motions required of the upper extremity and spine during the performance of the swimming activity. In cases of stroke technique error that are often seen among novice competitive swimmers and untrained recreational swimmers, there is a high incidence of unilateral trunk rotation and lateral sway. In many instances, these types of stroke errors in swimming technique can be responsible for the unequal development of the upper extremity girdle and thoracic musculature.

The functional scoliosis that is prevalent in swimmers often is accompanied by overdevelopment of one upper extremity, similar to the athletic scoliosis noted by Kuprian. Among athletes whose sports require extreme unilateral upper extremity torque and repetitive motions, it is questionable whether swimming is the activity of choice for scoliosis rehabilitation programs. Cobb, Keim, Kuprian, Roaf, and Tarr do not believe that exercise of any kind is beneficial to inhibiting the scoliotic development.

In 1941 the American Orthopedic Association Research Committee came to the conclusion, after a study of 425 cases of end-result idiopathic scoliosis, that exercise should be avoided. This study found that approximately 60 per cent of the patients treated with exercise had an increase in the deformity, and 40 per cent had no change. The support by Blount and Moe, Adams, and others for swimming as a scoliotic treatment is seemingly contradicted for the potential effects that may be imparted on the musculoskeletal system.

CONCLUSION

The evidence available for definite conclusions regarding the incidence of scoliosis among swimmers remains to be totally convincing, and the cause of the problem has yet to be determined. It is, however, obvious that the repetitive swimming activity will definitely cause adaptation of the primary structures and musculature, with the possibility that a secondary adaptation can occur in the vertebral structure. Although there has been no conclusive evidence to support the role hormonal development has played in the scoliotic curvature, the incidence among adolescents and preadolescents encourages study in this area. In addition, biomechanical assessment of stroke technique among swimmers should be an area of investigation, owing to the high incidence of mild curvatures, to determine if kinesthetics and/or hand dominance play a role in the etiology of scoliosis in swimmers.

The role of swimming as a therapeutic exercise in the treatment of scoliosis is definitely contraindicated, based on studies that show exercise has little effect on the reversal of the curvature. It is therefore assumed that competitive swimming may have a progressive effect on the curvature, if the athlete is training during the adolescent ages of 10 to 15 years. Although there are many factors that may contribute to the cause of scoliosis in swimmers, there is major evidence to indicate the mechanics of the strokes and the subsequent muscular adaptation due to the training can be significant contributors to the onset of scoliosis.

REFERENCES

Swimming

INJURY PREVENTION

The sport of synchronized swimming is probably the least known of the four aquatic sports. First begun as an art form in the water by Annette Kellerman in the early 1900's, and popularized by Esther Williams in 1939-1940, it developed into an AAU competitive sport in 1946, and finally achieved acceptance as an Olympic sport in 1984. Currently, competitive synchronized swimming is a sport for girls and women from early childhood into the mid-twenties. Masters competition includes men and women from age 20 onward, and there are no competitors near 80 years of age.

Synchronized swimming is relatively free of injury. The sport requires flexibility, kinesthetic awareness, and ability to hear musical rhythms, and an ability to perform repeatedly under anaerobic conditions with inadequate aerobic recovery time in between. It is a nonweightbearing sport, and it has neither the impact injury potential of diving nor the body contact injury potential of water polo. In the only study of injury rates that included synchronized swimming, a count of injuries incurred at a multisport Junior Olympic National Championships, there were 120 injuries among the approximately 200 who were synchronized swimmers.

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Medical Aspects of Synchronized Swimming

The sport of synchronized swimming is probably the least known of the four aquatic sports. First begun as an art form in the water by Annette Kellerman in the early 1900's, and popularized by Esther Williams in 1939-1940, it developed into an AAU competitive sport in 1946, and finally achieved acceptance as an Olympic sport in 1984. Currently, competitive synchronized swimming is a sport for girls and women from early childhood into the mid-twenties. Masters competition includes men and women from age 20 onward, and there are no competitors near 80 years of age.

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INJURY PREVENTION

Most injuries seen by coaches, trainers, or team physicians among synchronized swimmers are incurred outside the sport or are related to overuse. Additionally, physicians are often consulted in the areas of weight control, stress management, treatment of ear and eye problems, and minor acute illnesses. For these reasons, a preparticipation medical evaluation could be very helpful in alerting the coach about pre-existing conditions limiting flexibility or increasing the likelihood of knee or shoulder problems.

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