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The effect of rehabilitation exercises according to the bio-kinematic analysis of the subtalar joint after recovery from fibrosis resulting from a non-healing fracture in monofin swimming

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Abstract: This research aims to prepare rehabilitation exercises according to the bio-kinematic analysis of the subtalar joint during the performance of monofin swimming to recovery from fibrosis of the ankle joint resulting from an unhealed fracture in monofin swimming. The study concluded that the Ultrasound and Shockwave sessions, in addition to Stretching for the two legs, are among the most important, inexpensive and effective ways to help the joint return to its natural state, and as a result, the joint returned to its normal position and regained its ability to perform its normal functional tasks efficiently.

Keywords: Monofin, Bio-kinematic, Subtalar joint fibrosis, Rehabilitation exercises

1. Introduction

This research aims to prepare rehabilitation exercises according to the bio-kinematic analysis of the subtalar joint during the performance of monofin swimming to recovery from fibrosis of the ankle joint resulting from an unhealed fracture in monofin swimming. The study concluded that the Ultrasound and Shockwave sessions, in addition to Stretching for the two legs, are among the most important, inexpensive and effective ways to help the joint return to its natural state, and as a result, the joint returned to its normal position and regained its ability to perform its normal functional tasks efficiently.

The Monofin is a type of swimfin typically used in underwater sports such as finswimming, free-diving and underwater orienteering. It consists of a single or linked surfaces attached to both of the diver's feet. (Stavrou & Voutselas, 2018)

The subtalar joint consists of a joint between three inferior articular surfaces and three calcaneal joint surfaces (Tasto, 2004)

The subtalar joint acts as a bridge between the foot and the ankle, transferring loads from the foot to the leg or from the leg to the foot. (Tasto, 2004)

The subtalar joint is one of the synovial joints in the body, and it is one of the most commonly injured joints in athletes, and the subtalar joint surrounds many tendons and ligaments, making it more susceptible to continuous injury . (Krähenbühl et al., 2017)

Whereas the subtalar joint fracture is one of the five most common fractures in athletes .(Pfeifer et al., 2015)

Feeling of pain when moving also leads to restricting and limiting the range of motion of the joint, as it is considered a negative stimulus (Perez-Carro et al., 2021)

The Monofin swimming relies heavily on the ankle to make the two legs strokes, which push the swimmer's body forward while keeping the chest position fixe.(Rejman, 2013b)

And that any injury that causes pain in the body negatively affects the swimmer's performance, especially injuries to the lower extremity.

Where monofin swimming depends on the movement of the legs in the vertical plane continuously, which works to push the body on the horizontal plane, with the stability of the body and the absence of any movement on the sagittal plane.(Rejman, 2013b; E. A. (1) Saurov & Saurova, 2018)

The shape of the swimmer is greatly affected when the ankle joint is injured (Shimojo et al., 2019b), Injury to the ankle joint causes an imbalance in the flow of water around the legs, which reduces swimming speed and increases water resistance to it (El Baroudi & Razafimahery, 2014; NAKASHIMA et al., 2010)

Many studies have studied monofin swimming from a mechanical point of view because it has the ability to explain movement within the water (E. A. (1) Saurov & Saurova, 2018) Monofin swimming and the development of performance for swimmers through the mechanical analysis of the swimmer and the use of that data in teaching monofin swimming, and one of the most important results was to reach the critical mechanical variables in the performance of monofin swimming for elite swimmers, and the mechanical variables of the ankle joint were among the most important variables determining the speed of the swimmer.

While the study was adopted (Rejman, 2013b) On reaching the biomechanical variables to find errors in the performance of monofin swimming, and the study concluded that the errors in the far end of the fin are the most errors that reduce the speed of the swimmer. It depends mainly on the motor pathway of the ankle joint, which in turn controls the mechanics of the fin's work.

Also study of (Ikeda et al., 2021) did comparing the kinematics of dolphin leg stroke performance and monofin swimmer's leg stroke, the study proved the importance of the subtalar joint in determining the bio-kinematic path of the legs during monofin swimming, and it also has a significant impact on the swimmer's speed.

Also did a study of (Shimojo et al., 2019a) recognizing the importance of the flexibility of the lower extremity joints among monofin swimmers, especially the flexibility of the subtalar joint.

and study (E. A. Saurov & Saurova, 2018) The purpose of the study was to compare the performance technique during monofin swimming and traditional swimming, and one of its most important results was that monofin swimming depends largely on the number and strength of the two men’s strokes, which is the winning factor in this sport.

and study (Rejman, 2013a) By studying the error in the technique of monofin swimming performance, the results of which confirmed that the strikes of the legs originate in the thigh and then move to the knees and then to the ankle, which plays the role of the final paragraph in the open kinetic chain.

Through the work in the field of Biomechanic analysis and by conducting a kinetic analysis process for the Monofin swimming team at the “Al-Masry Club” in Port Said, has been noticed that the research sample undergoes a state of severe pain immediately after training

Despite the coach’s interest and changing the training methods and constantly changing the loads, the pain did not stop, and after doing an MRI of the legs, it became clear that there were traces of fibrosis resulting from an old unhealed fracture in the right foot. Fig. (1)

Figure 1. MRI subtalar joint fibrosis (right foot)

Therefore, the researchers intended to conduct a bio-kinematic analysis of the legs and apply qualitative rehabilitation exercises according to the bio-kinematic variables to strengthen the muscles of the feet, which may have an impact on developing and improving the work of the two legs and thus improving the performance of the research sample, as well as reducing pain when swimming.

2. Materials and Methods

Has been used the experimental method, using the experimental design for one group, using the pre- and post-measurement, for its relevance to the nature of the study. Table (1)

Table 1 Research symbols

Terms	symbol	Unit
Time	t	Sec
Angle	θ	Degree
Angular Velocity	θv	Degree
Horizontal displacement Component	x	m
Vertical displacement Component	y	m
Horizontal Velocity	Vx	m/sec
Vertical Velocity	Vy	m/sec
Absolute resulting Velocity	V	m/sec

2.1. Participant

The research was conducted on one of the monofin swimmers registered in the International Swimming Federation, who suffers from subtalar joint fibrosis resulting from an unhealed fracture. Table (2)

Table 2 Descriptive data

Sample	
Participant (n)	1
Age at test (year)	13.4
months since injury	19
Height (CM)	156
Weight (kg)	58
BMI (kg/m^2)	23.8
Score Time (second) at test	24.59

2.2. Data Processing

Video shooting (2D) using a Gopro hero4 black camera at 240 frames/sec and was filmed underwater .(HERO4 | GoPro, n.d.) Immediate bio-kinematic analysis system using a video camera and a computer through the Tracker program for bio-kinematic analysis (Tracker Video Analysis and Modeling Tool for Physics Education, n.d.). Fig. (2)

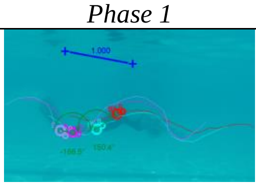
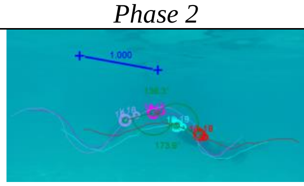
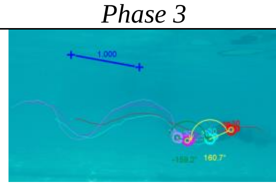
Phase 1	*Phase 2*	*Phase 3*
		
Knee joint (t, θ) Subtalar joint (t, x, y, v, vx, vy, θ, θv)	Knee joint (t, θ) Subtalar joint (t, x, y, v, vx, vy, θ, θv)	Knee joint (t, θ) Subtalar joint (t, x, y, v, vx, vy, θ, θv)

Figure 2. bio-kinematic model

2.3. Experimental Protocol

A therapeutic program has been implemented to strengthen the muscles of the legs, the aim of which is to get rid of the pain that accompanies performance and to develop swimming kinematics. The recovery procedures include five phases, as follows:

- **Myofascial release**, in which six sessions were performed, aimed at eliminating cramps in the feet and returning the foot to its normal state (Bac et al., 2022; Brandl et al., 2021)
- Stretching Where the flexibility of the lower extremity, especially the feet, is one of the important and influencing factors in the performance of the swimmer, and the flexibility of the feet is very effective, especially in the strikes of the legs under water .(Shen et al., 2022; Shimojo et al., 2019a)
- **Shockwave** Studies indicate (Hayano et al., 2021; Tognolo et al., 2022; van Doormaal et al., 2020) To the importance of shockwave in improving performance of swimmers, as studies have confirmed that shockwave works to get rid of the pain of the two legs and return the foot to normal after injury or excessive stress. It is one of the most important physiotherapy methods used, especially for skeletal muscles (Wang, 2012)
- **Ultrasound** It relieves pain quickly and directly, thus paving the way for treatment (Chen et al., 2022) This is in addition to the great uses and benefits of Ultrasound in the recovery and training process (Patey & Corcoran, 2021) ، Where the pain that a swimmer feels when suffering from cirrhosis is an obstacle to performance, and here is the role of Ultrasound in relieving the pain caused by inhibiting the nervous system and modifying its activity . (Rabut et al., 2020)
- **The monoroket**: the quality of Monofin Rocket is less weight and more effective, and it distributes the effort exerted on the fin evenly and effectively (Gea-García et al., 2020)

3. Results

Table 3 . Bio-kinematics analysis

Variables		Before				After			
		Phase 1	**Phase 2**	**Phase 3**	**Total**	**Phase 1**	**Phase 2**	**Phase 3**	**Total**
t		0.76	0.355	1.185	2.310	0.375	0.375	0.501	1.251
Knee angle	θ	135.42	179.10	166.95		150.36	173.88	160.68	
Subtalar Joint	X	1.96	3.00	2.87		2.34	3.16	3.91	
	Y	1.01	1.64	1.23		1.56	2.00	1.48	
	v	1.375	2.321	1.255		2.03	2.48	1.45	
	Vx	1.14	2.31	1.25		1.95	2.47	1.44	
	Vy	-0.77	0.23	-0.12		-0.56	0.272	-0.225	
	θv	-8.33	4.10	-8.174		-16.0	6.27	-8.88	
	θ	-113.46	102.25	-117.60		-166.5	136.29	-159.2	

4. Discussion

It is clear from table 3 that there is a general improvement in the performance of the sample under study in the bio-kinematic variables, as the time of performing the blow became about 54.15% less than the original time and this was confirmed by the results of the velocity obtained as well as the horizontal and vertical velocity of the Subtalar Joint, It is also clear that the time of the three phases of performance has decreased, and the researchers attribute this to the fact that the development in the performance time took place within all the three phases of performance, whether the first and third phases, which are the feet go down, or the second phase, which is the phase of the feet ascending to the top, which indicates the completion of hospitalization for the two men, as in In the first and third phases the feet perform the process of extension and are responsible for it Hamstrings muscles, while during the second phase the feet perform the process of flexion and are responsible for it Quadriceps group. (Marieb & Jackson, 2018; Netter, 1951)

This means that both the Extension and Flexion muscles are fully recovered. The researchers attribute this to the fact that the physical therapy used and the flexibility and strength exercises that were used rehabilitated the working muscles of Monofin. which agrees with (Fone & van den Tillaar, 2022; Hermosilla et al., 2021; Karpiński et al., 2020) In that the regular physiotherapy based on scientific foundations is a quick and inexpensive solution to recover from injuries and ensure that the injury does not develop and get rid of pain, and its effect is more noticeable more quickly on large muscles.

It is also clear that the ankle angle at all phases of performance was less than normal after the injury, while it returned to its normal position (Agoada & Kramer, 2019; Tomaro & Butterffield, 1995) And the ankle angle has increased significantly after recovery, as the Subtalar Joint is one of the Plane joint (Marieb & Jackson, 2018; Netter, 1951; Rockar, 1995) It is one of the highly affected joints when injured, and the injury causes it to reduce the angle of the foot, the inability to straighten the metatarsal at its natural angle .(Badalahu et al., 2020; Rockar, 1995) The results of the study indicate that the joint angle has returned to its normal position, which indicates the elimination of the effect of fibrosis resulting from an unhealed fracture that was not properly treated. Consistent with the results (Sata, 2012) Ultrasound and infrared are among the most important methods used as an alternative to ICSI in cases of fibrosis resulting from an unhealed fracture.

The researchers attribute the presence of a contraction in the subtalar joint angle to that the feeling of swimming pain during performance acted as a stimulus to inhibit the work of the foot and determine its angle (Li & Sun, 2021) ،Where pain is considered a stimulus to stop motor work (Abdellatif et al., 2021) And when she got rid of the pain caused by fibrosis, she was able to swim, straightening the feet in the most appropriate way for the motor and natural performance of the joint (Chean et al., 2021)

This is in addition to a clear and noticeable improvement in the angle of the knee joint during the three performance phases, as the knee angle decreased in the second and third phases, while the knee angle increased in the first phase after recovery, and the researchers attributed this to the fact that the first phase requires less range of motion than in the phase The third, where the strikes of the two legs are considered to be from the repetitive double movements, and the thrust of the two legs depends on the motor transfer of the amount of movement from the trunk to the foot, by using the lower end as an open chain of motion (Hoppenfeld et al., 2017)

which agrees with (Choi & Baek, 2020; Zhang et al., 2019) The return of the joint to its normal state helps in the performance of the joint for all its anatomical functions

It also agrees with the study (GRZĄDZIELA et al., 2020; Lin et al., 2021; Rejman, 2006) In the values of the ankle and knee angles that were inferred from the current study are the man's normal angles for monofin swimmers.

It is also clear from the results that the speed of the subtalar joint increased in the three phases of performance by about (76.73%, 93.58% and 86.55%), as the pain that the sample was feeling was causing a clear deficiency of performance, which leads to a decrease in swimming time. Performance speed with study (Nicolas & Bideau, 2009) In that the average speed of performance of two-legged strokes in underwater monofin swimming 2.45 m/sec

The results of this study are limited results on the study sample because of the specificity of this study, as it is based on the treatment of fibrosis in the subtalar joint resulting from an old unhealed fracture, which caused chronic pain in the study sample, and this case was dealt with through Ultrasound and Shockwave sessions, and the end of The problem of pain resulting from fibrosis was permanently eliminated, and the research sample was able to return to its normal state and the Subtalar Joint returned to its normal range of motion

5. Conclusions

Subtalar joint fibrosis is considered in the problems that cause great pain in swimmers and limit the angle of action of the foot, which impedes its proper, correct and normal performance. Ultrasound and Shockwave sessions, in addition to Stretching for leg ailments, are considered one of the most important, inexpensive and effective ways to help the joint return to its normal state.

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