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Araştırma Makalesi / Research Article

Dimension Optimization of Polycentric Knee Mechanism Using the Bees Algorithm and Genetic Algorithm

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ABSTRACT: In knee prostheses, the curve of the instantaneous center of rotation (ICR) and, therefore, stability of the prothesis are the most important parameters to be considered. The ICR curve depends on many parameters. One of them and the most effective one is the dimensions of four bar mechanism. In polycentric knee mechanisms, it has become inevitable to use optimization techniques while determining the dimensions of the mechanism for the stability of the prosthesis in the stance position. In this study, definitions of knee prostheses and polycentric knee mechanisms are given, optimization studies written in this field are mentioned thorough literature research. The study aims to find mechanism dimensions that gives ICR curve close to the reference curve by optimizing the mechanism dimensions of four-bar knee mechanisms. The Bees Algorithm and Genetic Algorithm (GA) were used for this purpose. The limits and objective function for the optimization were determined, and after many trials, separate mechanism dimensions with The Bees Algorithm and the Genetic Algorithm are obtained. By comparing the results, it has been observed that the dimensions obtained by The Bees Algorithm produced a better approximation to the reference instantaneous center of rotation curve.

Keywords: Knee Prosthesis, Polycentric Knee, Four-Bar Mechanism, Lower-Limb Prosthesis, Voluntary Control, Instantaneous Center of Rotation

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Dört Çubuk Mekanizmalı Diz Protezlerinin Arı Algoritması ve Genetik Algoritma ile Boyut Optimizasyonu

ÖZET: Diz protezlerinde kullanılan dört çubuk mekanizmalarda duruş durumunda ani dönme merkezi koordinatları ve buna bağlı olarak amputenin dengesi dikkat edilmesi gereken en önemli parametredir. Ani dönme merkezi eğrisi birçok parametreye bağlıdır. Bunların arasından dikkat edilmesi gereken en önemli parametrelerden biri de mekanizmanın boyutlarından geçmektedir. Dört çubuk mekanizmasının kullanıldığı diz protezlerinde duruş konumunda amputenin dengede olması için mekanizmanın boyutları belirlenirken optimizasyon tekniklerinin kullanılması kaçınılmaz bir hal almıştır. Bu çalışmada, diz protezleri ve diz protezlerinde kullanılan dört çubuk mekanizmaları hakkında tanımlamalar verilmiş, literatür araştırması yaparak bu alanda yazılan optimizasyon çalışmalarından bahsedilmiştir. Yapılan çalışma, diz protezlerinde kullanılan dört çubuk mekanizmanın sentezini yaparak referans ani dönme merkezi eğrisine yakın mekanizma boyutları bulmayı amaçlamaktadır. Mekanizma boyutları için Arı Algoritması ve Genetik Algoritma kullanılmıştır. Optimizasyon için gerekli sınırlar ve amaç fonksiyonu belirlenmiş, birçok deneme sonrası Arı Algoritması ve Genetik Algoritma için ayrı ayrı mekanizma boyutları elde edilmiştir. Elde edilen sonuçlar karşılaştırılmış ve Arı Algoritmasının referans ani dönme merkezi eğrisine daha iyi yakınlaşan mekanizma boyutları verdiği görülmüştür.

Anahtar Kelimeler: Diz Protezleri, Çok Merkezli Diz Mekanizması, Dört Çubuk Mekanizması, Alt-Ekstremite Protezi, Gönüllü Kontrol, Ani Dönme Merkezi

1. INTRODUCTION

Walking and running are one of the daily activities for humans. In transfemoral amputees, on the other hand, the best way to gain walking ability is to use knee prostheses. In these prostheses, the most important factor affecting walking and performance is the knee mechanism (El-Sayed et al., 2014). Knee prostheses are generally divided into passive and active knee prostheses with respect to the power requirement. Active knee prostheses have a motor or actuator unlike passive knee prostheses which increases the weight and volume of the knee prosthesis and shortens the operating time of the prosthesis due to the battery capacity. Passive knee prostheses, on the other hand, are more used in the commercial field since there is no need for batteries (Fu et al., 2016). Knee prostheses are further divided into two as single axis and polycentric prosthetic knee mechanisms with respect to their functions (Radcliffe 1994). Although single axis (monocentric) knee mechanisms are cheaper, simpler, and smaller, their control is limited since they have fixed axes of rotation. This causes an unstable and unnatural gait. While polycentric knee mechanisms are expensive compared to single axis knee mechanisms, they are easy to control since they have the curve of the instantaneous center of rotation (ICR) that provide stability in the stance and swing phases of the prosthesis (Chauhan and Bhaduri 2011). The four-bar mechanism, which is a polycentric knee mechanism, is widely used in knee prostheses due to its simplicity. To assure stability, polycentric knee mechanisms must meet the following factors: length and strength of the remaining limb, the fitting of the socket, position of the hip joint relative to the knee and ankle joints of the prosthesis, and functional characteristics of the knee and foot-ankle mechanisms included in the prosthesis (Radcliffe 2003).

There are many studies on four-bar mechanisms in the literature. Since the meta-heuristic optimization techniques that have developed and increased in recent years, optimization studies of the ICR curve and path synthesis of the four-bar mechanism have increased in number. Some of these studies are given below.

Anand T.S. and Sujatha S. stated that they made the dimension optimization of the four-bar mechanism according to six different parameters using multi-objective Genetic Algorithm and compared it with the commercially used four-bar knee mechanisms in terms of toe tolerance, maximum knee extension and the stability of the knee prosthesis. As a result of the comparison, they indicated that the four-bar mechanism they designed was the best among others according to the parameters they chose (Anand and Sujatha, 2017). Roy et al. obtained the desired path of the four-bar mechanism by optimizing the dimensions of the mechanism with the Genetic Algorithm. They wrote the objective function as the sum of the squares of the difference of the path coordinates of the desired and obtained mechanism. In addition, they compared the paths of the four-bar mechanisms obtained before and after optimization (Roy et al., 2008). Soriano et al. using videogrammetry, put sensors on the ankle, knee, and hip of a few healthy individuals to examine their gait patterns. As a result of their examination, they deduced the curve of the ICR of the knee. They used linear regression method on these curves and applied Genetic Algorithm for dimension optimization of four-bar knee mechanism. They stated that the objective function was determined for voluntary control four-bar knee mechanism and the stability of the knee prosthesis. As a constraint, they determined a control area for voluntary control four-bar knee mechanism. Then, they compared the obtained four-bar knee mechanism with four different four-bar knee mechanism used in the commercial field (Soriano et al., 2020). Pfeifer et al., performed an optimization study for the torque profile of four different mechanisms used in active knee prostheses. They wrote that they chose the objective function as the sum of the squares of the difference between the desired torque profile and the obtained torque profile, through the flexion angle of the knee. As a result of their study, they indicated that the single axis knee mechanism gives the highest torque value, while the four-bar mechanism gives an almost uniform torque profile throughout the movement of the knee (Pfeifer et al., 2012). Şen M. A. made a dimension optimization study of the four-bar mechanism using Whale Optimization Algorithm (WOA) for the path synthesis of mechanism. He chose the reference curve as a circumscribed trajectory with a certain portion as a line segment. He expressed the objective function by mean value of the absolute error values along the x-axis between the reference trajectory and the actual trajectory. In addition, the results obtained after the optimization were compared with the results before the optimization (Şen 2021). Eqra et al. performed an optimization study for path synthesis of four-bar mechanisms using four different algorithms. They reported that the best results were obtained with AIW-PSO. They determined the objective function as the square of the sum of the difference between the reference path coordinates and the obtained path coordinates. They arranged the objective function for both open and crossed four-bar mechanism (Eqra et al., 2018). Muñoz-César et al. used the Taboo Search Algorithm and made dimension optimization of the voluntary control four-bar knee mechanism. They defined the objective function as the quadratic error of the difference between the reference ICR curve and the calculated ICR curve. In addition, they manufactured and applied the optimized knee prosthesis for a user whose left leg was amputated (Muñoz-César et al., 2013). Marisami P. and Venkatachalam R. synthesized a polycentric knee mechanism to improve the toe-clearance at mid-swing with optimizing dimensions of the mechanism by Evolutionary Algorithm. They used both the fixed and moving trajectories of the four-bar mechanism as parameters; they also wrote that, by creating a radar diagram over some parameters with commercial knee prostheses, the mechanism they obtained scored, in overall higher than the most available mechanisms (Marisami and Venkatachalam, 2022). Poliakov et al., obtained an appropriate Pareto solution set by means of the PSI Algorithm for the dimensions of four-bar knee mechanism. A multi-criteria dimension optimization study was performed for the reference ICR curve and the reference mechanism path. However, the four-bar mechanism they obtained as a result of the optimization is not fully suitable for use in knee prostheses unless the exact desired parameters are given (Poliakov et al., 2013). Different from the others, Yonghong et al. studied the six-bar mechanism for knee prosthesis and stated that they obtained the values of the knee and ankle angles of thirty different healthy individuals in the gait analysis by using motion capture technology. They also indicated that they chose the six-bar mechanism to better mimic the movement of the human knee in the configuration of the knee prosthesis. They used Genetic Algorithm for the dimension optimization of the six-bar mechanism and formed the objective function by the least square method using the values obtained from the gait analysis and the ICR curve of the ideal human knee (Zhang et al., 2021).

In the studies given above, optimization works of the four-bar mechanisms used and not used in knee prostheses were carried out by using different objective functions and different optimization techniques. The other studies that implemented the optimization techniques to their work in literature did not perform any comparison with other algorithms. This may lead to think if the results from the optimizations are the best or not. However, in this study we used the results of the most used algorithm in this area which is The Genetic Algorithm and compared it with The Bees Algorithm which is succesfull in local search. The suitability of The Bees Algorithm for use in this area has been mentioned by optimizing the dimensions of four-bar knee mechanisms according to the ICR curve of the mechanisms.

2. MATERIALS AND METHODS

2.1. Polycentric Knee Mechanisms

The four-bar knee mechanism, which is one of the polycentric knee mechanisms is divided into three as follows (Al-Maliky and Chiad, 2021): the hyper-stabilized four bar knee mechanism, voluntary control four bar mechanism, and the four-bar mechanism with elevated instantaneous center. A schematic of these three types of four-bar mechanisms is given in Figure 1.

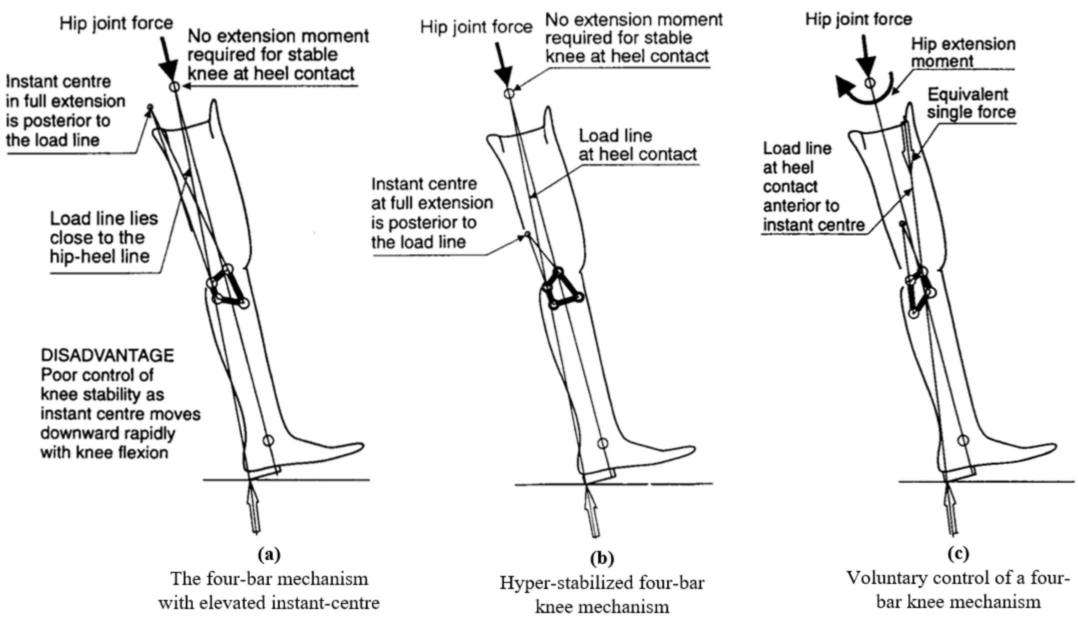

Figure 1. Four-bar mechanisms used in knee prosthesis (Radcliffe 1994).

While the four-bar mechanism with elevated instantaneous center provides stability at the heel contact, the hyper-stabilized four bar knee mechanism functions as fixed knee mechanism to ensure durability for less active amputees. Compared to the other two, for the voluntary control four-bar mechanism, amputee applies hip moment. However, this four-rod mechanism gives freedom to the amputee since the ICR can be controlled by the user both at heel contact and at push-off. This mechanism used in knee prosthesis is preferred by aggressively active amputees (Andrysek et al., 2011). In the commercial and academic fields, the voluntary control four-bar knee mechanism is used more than others.

The voluntary control four-bar knee mechanism has control area that allows the amputee to control the stability and position of the prosthetic knee in stance phase stages (Sancisi et al., 2009).

One of the voluntary control four-bar knee mechanism that is used in commercial area is Otto Bock 3R20 knee prosthesis. The Otto Bock 3R20 knee prosthesis is designed to provide stability and mobility for individuals with lower limb amputations. Here are some specifications of the Otto Bock 3R20 knee prosthesis:

- Weight: The weight of the 3R20 knee prosthesis for the stainless steel material is approximately 690 grams.
- Mechanical Design: It features a four-bar linkage mechanism that allows for controlled movement and stability during various activities.
- Flexion/Extension Range: The knee prosthesis offers a flexion range of approximately 110 degrees, allowing for natural movement during walking, sitting, and other activities.
- Stance Control: The 3R20 knee prosthesis incorporates a stance control feature that provides stability and control during the stance phase of walking.
- Compatibility: It is compatible with various prosthetic components and can be customized to fit individual user needs and preferences (Otto Bock 3R20/3R36 User Manuel, n.d.).

The Otto Bock 3R20 knee prosthesis is given in Figure 2.

Figure 2. Otto Bock 3r20 knee prosthesis (Otto Bock 3R20, n.d.).

In this study, using the ICR curve of the Otto Bock 3R20 knee prosthesis as reference, which is used in the commercial area and a voluntary control four-bar knee mechanism, mechanism dimensions suitable for the curve were obtained with two different algorithms. The reason for choosing this particular knee prosthesis is twofold: it is widely used in the commercial field, and it has also been taken as the reference ICR curve in (Al-Maliky and Chiad, 2021). In this study, different optimization methods were employed with the four-bar mechanism to successfully achieve the same curve.

2.2. Displacement Analysis of the Mechanism

The configuration of the four-bar mechanism used in knee prostheses is given in Figure 3. The dimensions of four bar links are as follows: s, h, k, and v, where “s” is the link 1, “h” is the link 2, “k” is the link 3 and “v” is link 4.

Centrode points of the joints of four-bar mechanism are as follows: A, B, C and D. The upper link BC is connected to socket part. On the other hand, the shank is connected to the lower link AD. The angles θ_1, θ_2, θ_3 and θ_4 are the rotation angles of the links s, h, k, and v respectively. One of the rotating joint points, A, is selected as [0,0] in Cartesian coordinates. ICR coordinates defined as G_{ICR}. The AD link of the mechanism was taken as fixed. The relationship between θ_E, the knee flexion angle and θ_3, the rotation angle of link BC can be written as $\theta_3 = \theta_E + \beta$, where β is the starting angle of the knee when $\theta_E = 0$.

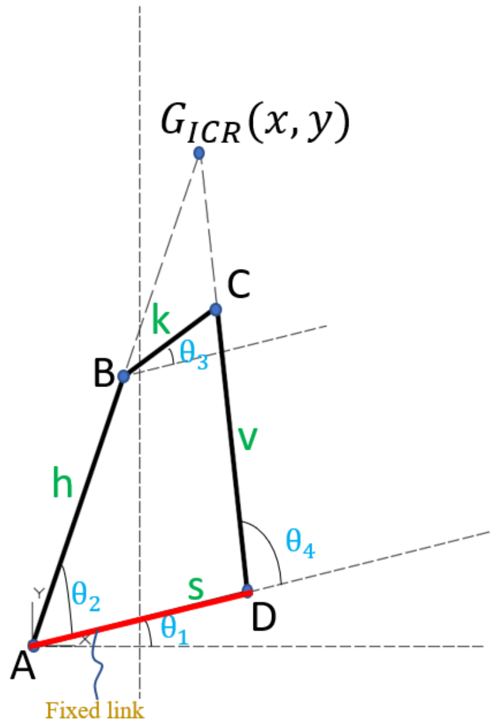

Figure 3. Configuration of four-bar mechanism.

During the movement, the BC link rotates at an angle of θ_3 and determined as the driving angle. The following equations are written according to the method proposed by Hobson and Torfason for the coordinates of the ICR of four-bar mechanisms (Hobson ve Torfason, 1974).

$$h\cos(\theta_2) + k\cos(\theta_3) = v\cos(\theta_4) + s \tag{1}$$

$$h\sin(\theta_2) + k\sin(\theta_3) = v\sin(\theta_4) \tag{2}$$

By examining the configuration of the mechanism, the relationship between the rotation angles of the second and third links is written from equations (1) and (2):

$$\mathrm{E}\sin(\theta_2) + F\cos(\theta_2) = P \tag{3}$$

Here;

$$\mathrm{E} = \sin(\theta_3) \tag{4}$$

$$\mathrm{F} = \cos(\theta_3) - \frac{s}{k} \tag{5}$$

$$\mathrm{P} = -\frac{s^2+h^2+k^2-v^2}{2\,h\,k} + \frac{s}{h}\cos(\theta_3) \tag{6}$$

By making an abbreviation, θ_2, which is the angle of rotation of the link h, and as a function of θ_2, θ_4 is written as follows:

$$V = \sqrt{E^2 + F^2 - P^2} \tag{7}$$

$$\theta_2 = 2tan^{-1}\left(\frac{E \pm V}{F+P}\right) \tag{8}$$

$$\theta_4 = sin^{-1}\left(\frac{h\sin(\theta_2)+k\sin(\theta_2)}{v}\right) \tag{9}$$

$$\theta_4 = cos^{-1}\left(\frac{h\cos(\theta_2)+k\cos(\theta_3)-s}{v}\right) \tag{10}$$

There are two different solutions of θ_2 from equation (8). Both solutions give different types of four-bar mechanism. By choosing one of these values, the angle θ_4 is found.

By using the equations given above, the coordinates of G_{ICR}, which is the coordinates of ICR, can be written as follows:

$$\mathrm{G}_x = \left[\frac{\tan(\theta_1+\theta_4)\cos(\theta_1)-\sin(\theta_1)}{\tan(\theta_1+\theta_4)-\tan(\theta_1+\theta_2)}\right]s \tag{11}$$

$$\mathrm{G}_y = \left[\frac{\tan(\theta_1+\theta_2)[\tan(\theta_1+\theta_4)\cos(\theta_1)-\sin(\theta_1)]}{\tan(\theta_1+\theta_4)-\tan(\theta_1+\theta_2)}\right]s \tag{12}$$

In this study, $\theta_1 = 5°$ was taken and the equations were solved in the MATLAB program.

2.3. Dimension Optimization of Knee Mechanism

In this section, dimension optimization of the four-bar knee mechanism has been studied by using Genetic Algorithm and The Bees Algorithm.

The constraints for the desired results are given below:

- The four-bar mechanisms used in the knee prostheses must act as double rocker. According to Grashof's Law, if the mechanism is a double rocker, the relationship between link dimensions can be defined as $l_{min} + l_{max} < l' + l''$. Here, l_{min} represents link "k" of the mechanism whose configuration is given in Figure 2.

- If the ICR of the mechanism is desired to remain high up to $\theta_E = 15° - 20°$, the constraint $h \leq v$ can be written (Chauhan ve Bhaduri, 2011).
- Considering the aesthetics of the mechanism, the limitations determined for the mechanism dimensions are given in Table 1 (Anand ve Sujatha, 2017).

Table 1. Dimension limits of the four-bar knee mechanism.

	s	h	k	v
Minimum	15	30	11	35
Maximum	25	40	14	50

The reason for choosing this dimension limits for the optimization work, is to find a smaller and lighter four-bar knee mechanism than Otto Bock 3R20 knee prosthesis that can approximate the reference ICR curve as much as possible. This is why the dimension limits of the shortest link "k" are chosen this close.

According to the limitations given in Table 1, the objective function is given in equation (13).

$$AF = \sum_1^n \left[\left(X_{RG_i} - X_{G_i}\right)^2 + \left(Y_{RG_i} - Y_{G_i}\right)^2 \right] + \sum_1^n \left(f_{H_i}\right) \tag{13}$$

Here, n is chosen to be the flexion angle values of the knee at the stance position. The objective function was determined as the sum of the square of differences between "x" and "y" coordinates of reference ICR and obtained ICR curve. That is, the least square method is used. Here, f_{H_i} represents the penalty function for Grashof's Law for double rocker.

In this study, the ICR curve of the Otto Bock 3R20 knee prosthesis was selected as a reference. The reference ICR curve is given in Figure 4.

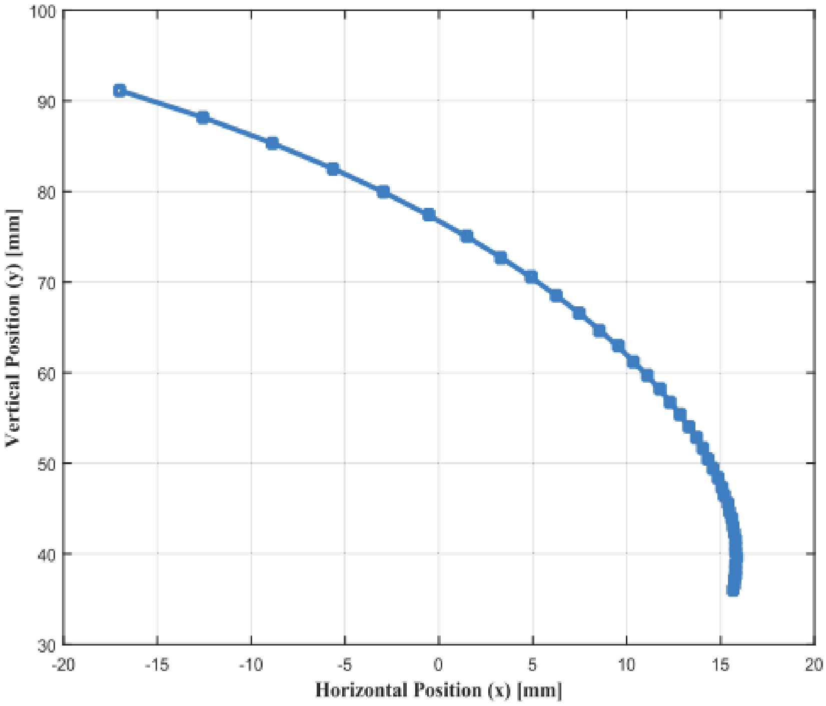

Figure 4. ICR curve of Otto Bock 3R20 at stance phase (Al-Maliky ve Chiad, 2021).

2.3.1. Dimension optimization with genetic algorithm

In this sub-section, the process of the Genetic Algorithm (GA) and the application of the determined objective function according to the limits are briefly explained.

In Figure 5, the flowchart of the Genetic Algorithm is given. As shown in below, the process is repeated until the iteration is over or the appropriate solution is found. Although Genetic Algorithm may not find the accurate answer as it works according to the rules of probability, it is used to solve problems that are difficult or impossible to solve with traditional methods (Holland 1992; İlgen et al., 2022).

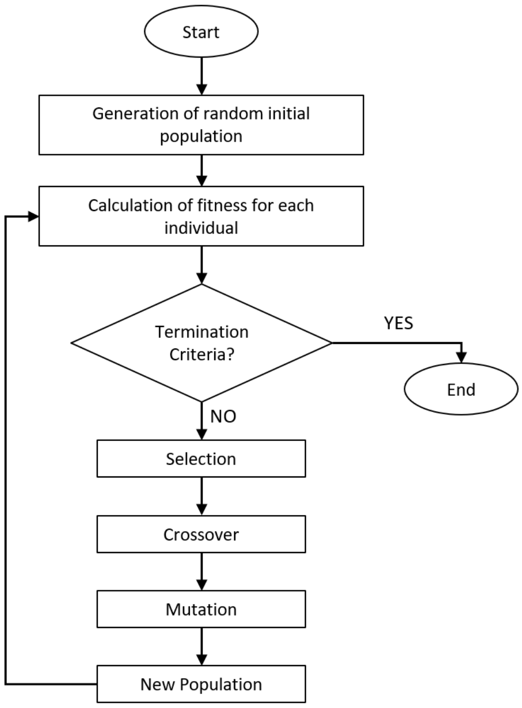

Figure 5. The flowchart of Genetic Algorithm.

2.3.2. Dimension optimization with The Bees Algorithm

Proposed by Pham et al., The Bees Algorithm is a population-based search algorithm that imitates the resource-seeking behavior of honeybees. An example of such interactive behavior is that honeybees share information about the quality of the source (nectar, water, etc.) they find by performing bee dance. Bees that find a high-quality source through this dance, share their direction, distance, and nectar amount information about this source with other bees. With the help of this mechanism, the colony can be directed to sites with high quality resources (Pham et al., 2005, 2006). Pham and Kalyoncu made a study to control a flexible link robot manipulator using PID and The Bees Algorithm based Fuzzy Logic controllers. Using The Bees Algorithm, this work is the first experimental and theoretical study for controller optimization (Pham et al., 2008; Pham ve Kalyoncu, 2009). For the evaluation of the suitability of The Bees Algorithm in controller optimization area, Şen and Kalyoncu designed PID and LQR controller with The Bees Algorithm for the optimization of inverted pendulum system (Şen et al., 2016; Şen and Kalyoncu, 2015). As a result of these studies, it is observed that The Bees Algorithm gives appropriate results in the designing of the controller parameters and compared to the traditional methods the position control of the system is improved. Eser et al. carried out optimization studies to reduce the deviations in the suspension system to achieve better driving ability and comfort of the quarter vehicle suspension system in the road map. They compared the deviations using The Bees Algorithm and Particle Swarm Optimization and stated that The Bees Algorithm gave more successful results (Eser et al., 2021).

There are many parameters in the working principle of the Bee Algorithm. These are:

- n: The number of scout bees.
- m: Number of sites selected from "n" points visited.
- e: The number of elite sites in the selected m sites.
- nep: The number of bees sent to the best e site.
- nsp: The number of bees sent to the remaining (m-e) site.
- ngh: size of the site.
- iter: stop criteria number or iterations (Eser et al., 2021; Pham et al., 2006).

The flowchart of The Bees Algorithm is given in Figure 6.

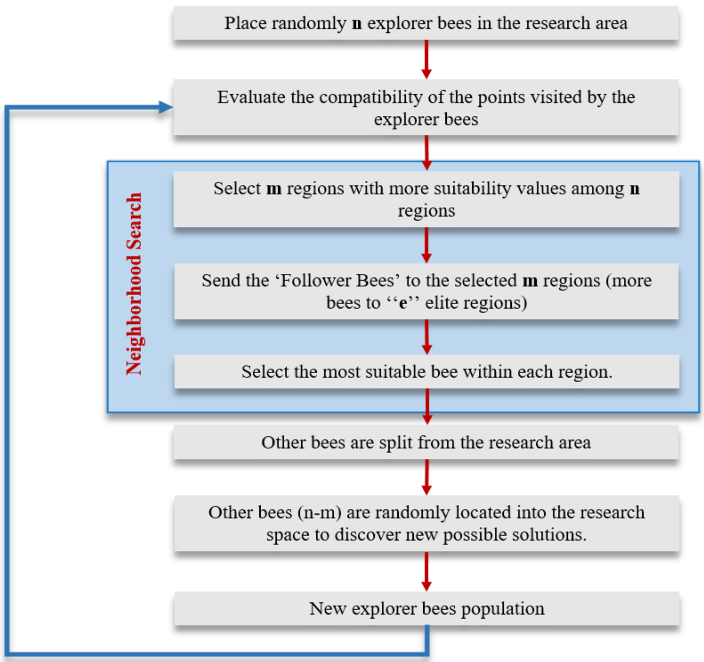

Figure 6. The flowchart of The Bees Algorithm.

The steps of flowchart in detail are given below:

1) Create a randomly generated population in space, adhering to constraints.
2) Calculate the error of the population and sort from smallest to largest.
3) Continue the loop until the stop condition is met.
4) Select the best populated areas for neighborhood search.
5) Send bees to the neighborhoods of the best populated regions and calculate the error of each bee.
6) Sort the error of each neighborhood group from smallest to largest.
7) Randomly distribute the remaining bees back to space considering the constraints and calculate their errors.
8) Start the loop again (go to step 3)

Table 2. Parameters of The Bees Algorithm.

n	m	e	nep	nsp	ngh	itr
80	12	5	2	4	0.01	105

3. RESULTS AND DISCUSSION

In this section, the dimension optimization of the four-bar knee mechanism is made according to the limitations, objective function and algorithm parameters given above. Reference curve is taken as the ICR curve of the Otto Bock 3R20 knee prosthesis. With MATLAB software, Genetic Algorithm which is widely used in the literature and The Bees Algorithm are compared for the dimension optimization of the four-bar knee mechanisms. The other studies that implemented the optimization techniques to their work in literature did not perform any comparison with other algorithms. This may lead to think if the results from the optimizations are the best or not. However, in this study we used the results of the most used algorithm in this area which is The Genetic Algorithm and compared it with The Bees Algorithm which is successful in local search. The aim in this study is to evaluate the suitability of The Bees Algorithm in knee mechanisms. The initial angle of the first link $\theta_1 = 5°$ was chosen. The limitations are given in Table 1.

In Figure 7, using both algorithms, the convergence graph of the dimension optimization study of the four-bar knee mechanism is given.

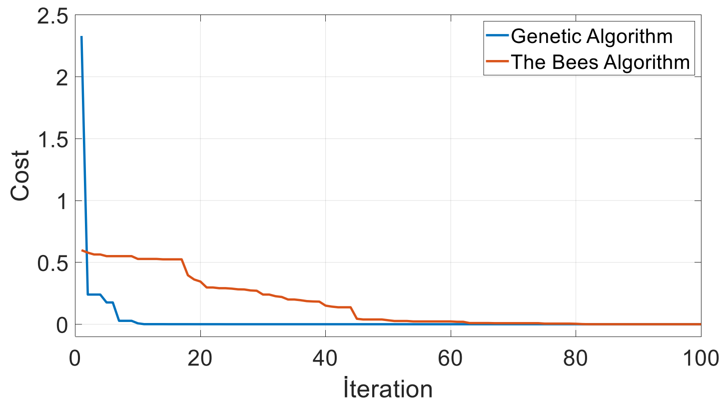

Figure 7. Convergence graph of the optimization study with The Bees Algorithm and Genetic Algorithm.

In Figure 8, the reference ICR curve compared with the ICR curves obtained from optimization with Genetic Algorithm and The Bees Algorithm. In Table 3, the dimensions obtained after optimization using Genetic Algorithm and The Bees Algorithm are given.

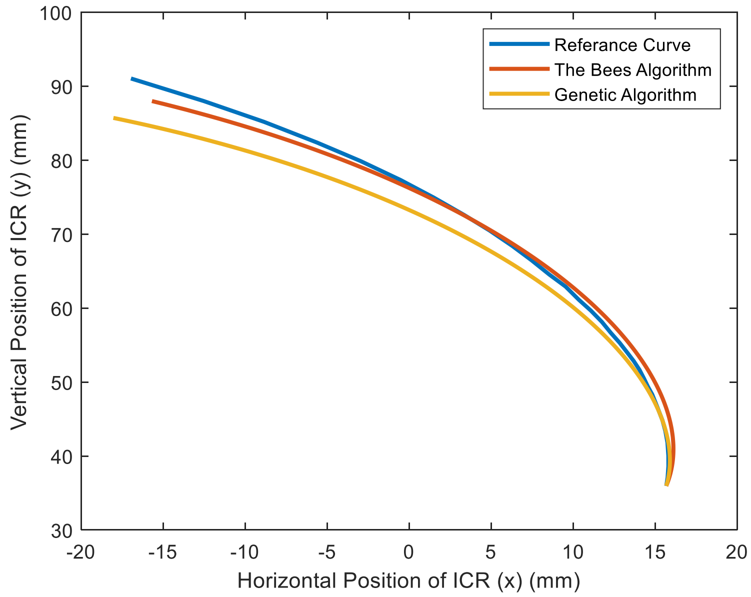

Figure 8. Comparison of ICR curves.

Table 3. Mechanism dimensions obtained using Genetic Algorithm and The Bees Algorithm.

	s	**h**	**k**	**v**
Genetic Algorithm	20.7465 mm	34.0135 mm	12.0544 mm	41.8178 mm
The Bees Algorithm	19.1815 mm	34.9417 mm	11.3698 mm	41.8924 mm

In the convergence graph seen in Figure 7, the Genetic Algorithm converged to the result in less iterations than The Bees Algorithm. However, in the comparison given in Figure 8, optimization results using The Bees Algorithm are closer to the reference curve than optimization results using Genetic Algorithm. The reason for this is that The Bees Algorithm makes a more sensitive search in smaller areas and converges to the optimum values higher.

4. CONCLUSION

In this study, determining the reference as ICR curve of Otto Bock 3R20 knee mechanism at stance phase, an optimization comparison was done for the mechanism dimensions by using The Bees Algorithm and Genetic Algorithm. The constraints required for the aesthetic aspects of the mechanism and for the use of the mechanism in knee prostheses were determined, penalty functions were written, and the necessary objective function was defined according to these parameters. Parameters of The Bees Algorithm are defined. After many optimizations attempts with The Bees Algorithm and Genetic Algorithm, the minimum and maximum limits of the mechanism dimensions were updated, and appropriate results have obtained in less iterations. As a result of the comparison of both algorithms, it was seen that The Bees Algorithm reached the appropriate result at higher iterations than Genetic Algorithm. However, more accurate mechanism dimensions were obtained with The Bees Algorithm in approaching the reference curve.

In this study, it was seen that The Bees Algorithm gave a suitable result for the four-bar mechanisms used in knee prostheses. As a result, it can be said that The Bees Algorithm can be applied to four-bar knee mechanisms.

5. CONFLICT OF INTEREST

Authors approve that to the best of their knowledge, there is not any conflict of interest or common interest with an institution/organization or a person that may affect the review process of the paper.

6. AUTHOR CONTRIBUTION

Mert Eren AYĞAHOĞLU performed the synthesis of the four-bar knee mechanism and wrote the paper. Mert Eren AYĞAHOĞLU, Abdullah ÇAKAN and Mehmet Sefa GÜMÜŞ contributed to the optimization of the knee prosthesis, process of the research, research management and interpretation of the results. Mete KALYONCU contributed to determine the concept of the research and research management and final approval of the research.

7. REFERENCES

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