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Evaluation of Gait Characteristics of Patient Subjected to the Atrophic Jaw Augmentation

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***Abstract*—Reconstruction of hyperatropic jaws for the rehabilitation of patients with dental implant aided fixed prosthodontics must be three dimensional. High volume donor site is required for the reconstruction of hyperatropic jaws. Although tibia, fibula, cranium and ribs can be used for these kinds of operations, iliac crest is the most preferred donor site due to its high bone volume, relatively ease of operation and low morbidity and complication incidence. Although the augmentation operations, which are performed by using iliac crest, are routine and successful on oral and maxillofacial surgery field, these operations have their peculiar complications. Among these complications, gait disturbances are the most frequent. The aim of this research is to define the gait and muscle forces characteristics of these patients. To do so, kinematic, kinetic and temporal-spatial gait parameters of the patients during pre- and postoperative periods were recorded and restoring process of preoperative gait patterns was quantitatively evaluated by analyzing the gait data and using the Opensim software. This paper presents the evaluation the first results of the ongoing study.**

Keywords- iliac crest, bone, augmentation, graft, gait analysis, opensim

INTRODUCTION

Iliac crest is regarded as a gold standard on maxillofacial surgery field as a bone graft donor site [1], [2]. Due to the easily isolation of the operation field and relatively easy technique, this region is the most preferred donor site in such operations [3]. However, due to the trauma occurring in anatomical structures especially in muscle-bone connection sites, gait abnormalities in patients are observed in the post-operative periods. Gluteus medius (GMED), gluteus maximus (GMAX) and iliopsoas (ILIOP) are the most susceptible muscles to the trauma, because these muscles are located in close vicinity to the graft donor site.

Hyperatropic jaw bone graft requires the bicortical structure of 6x5cm average size for the reconstruction [4], [5]. At this point, the GMED, GMAX and ILIOP muscl]es must be individually separated from the bone surface to have graft tissue which leads to the gait abnormalities. These disorders recover on average 1-2 months after surgery and patients regain their preoperative gait characteristics. Since there many factors affecting the recovery process, it is difficult to identify the process exactly.

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The purpose of this study is to identify the gait abnormalities of patients who undergo atrophic jaw augmentation operation in which the iliac crest is used as donor sites for augmentation procedure. This paper gives and discusses the first results of the ongoing study.

MATERIAL AND METHODS

A. Gait Experiments

Since the bone graft was taken from the iliac crest, it was assumed that the distinctive variations between the pre- and postoperative gait parameters occur around hip joint and hence, kinematic and kinetic parameters were compared for the hip joint. To be able to have an objective comparison between patients' kinematic and kinetic data, operation was planned to perform in a standardize way such that the same amount of bone graft was taken by the same surgeon and by the same operational technique. Ten patients were included to the study. To share the first results of this ongoing research, this paper reports only one representative subject's results.

Each participant underwent gait parameter assessment at a self-selected speed at the Istanbul University, Faculty of Medicine, Motion Analysis Laboratory. The representative gait data were collected from a male subject (age: 27 years, height: 170cm; mass: 72kg) during pre- and post operative periods. Patient was asked to walk as a natural way in the laboratory. Two post operative periods was specified as one-week (post-op1) and two-week (post-op2) after the surgery. By doing so, it was aimed to determine when the abnormal gait function returns to normal characteristics. To record the patient's movement in three dimensional (3D) gait/motion analysis system, the passive markers, of which trajectories were perceived by infrared cameras, were mounted on the specific anatomic regions. Ground reaction force, which is basically the reaction to the force the body exerts on the ground, was also measured simultaneously using two force plates. A six-camera motion analysis system (ELITE2002; BTS, Milan, Italy) and two force-plates (Kistler Switzerland) were utilized for each participant.

B. Analysis in Opensim

The human musculoskeletal model, which is currently available in Opensim library, was used in our analyses [6]. This model has 23 degree-of-freedoms (DoF) and 10 segments.

Static optimization (SO) and computed muscle control (CMC) were implemented separately in the calculation of muscle forces. In SO, a cost function, which is subjected to some physiological based constraints, is optimized independently for each time point of interest [7], [8]. In the present study, SO was implemented by minimizing the sum of the squares of all muscle activations at each instant of the stance phase. CMC produces a forward simulation of the prescribed task by using a proportional-integral controller to track the joint angular accelerations measured from a gait tasks. Prior to calculation of muscle forces, joint angles and joint moments were computed. Joint angles were obtained from using the inverse kinematics technique. Once the joint angles were computed, measured ground reactions forces and joint angles were entered to the inverse dynamics process and then joint moments were calculated [9].

RESULTS AND DISCUSSIONS

Since the grafting operation took place in the right iliac crest of the body, all spatio-temporal, kinematic and kinetic parameters were determined for the right side of the body.

Means of the pre- and post-operative spatio-temporal gait parameters, which were recorded from three different trials, are given in Table 1. These three trials were selected such that the right foot soles were entirely in contact with the force plates during natural walking characteristics. It can be observed from the table that all spatio-temporal parameters measured in the post-op2 are closer to those in the pre-op than those in Post-op1 which denotes that the treatment process applied to patient showed a successful performance.

Table 1. Mean (± standard deviation) values of spatio-temporal gait parameters obtained during pre-op, post-op1 and post-op2 periods.

Spatio-temporal Parameters	**Pre-op Mean±STD**	**Post-op1 Mean±STD**	**Post-op2 Mean±STD**
Stance time [ms]	805±30.41	623±96.9	750±26.4
Swing time [ms]	565±25.9	531.6±59.2	503.3±15.2
Stance time [% Gait Cycle]	58.6±0.5	54±5.5	59.6±1.1
Swing time [% Gait Cycle]	41.3±0.5	46±5.5	40.3±1.1
Cadence [step/min]	88±2.6	105±7.5	96±2
Double support time [ms]	115±13.2	176.6±55.0	130±17.3
Double support [% Gait Cycle]	8.3±1.1	15±3.6	10.3±1.1
Anterior step length [mm]	553.3±37.1	344.6±19.8	600.6±19.6
Swing velocity [m/s]	2.0±0.0	1.1±0.1	2.3±0.0
Stride length [mm]	1148.6±37.8	626.6±21.5	1185.6±36.8
Step width [mm]	143±2	202±10.8	152±4
Mean velocity [m/s]	0.8±0.0	0.54±0.0	0.9±0.0

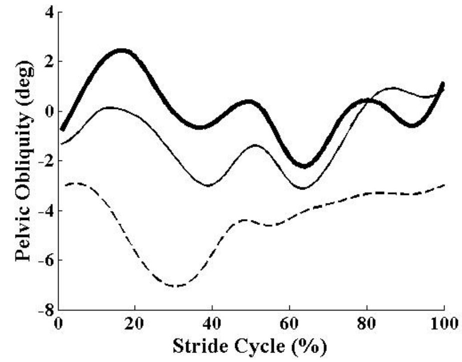
Mean values of the kinematic gait parameters are given in Table 2. As similar as in spatio-temporal parameters, kinematic parameters measured in the post-op2 are closer to those in the pre-op than those in Post-op1.

Table 2. Mean (± standard deviation) values of kinematic gait parameters obtained during pre-op, post-op1 and post-op2 periods.

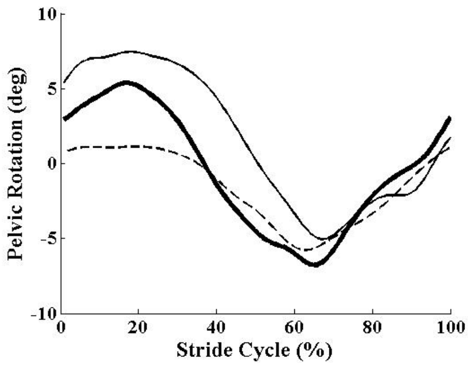
Kinematics Parameters	Pre-op Mean±STD [Degree]	Post-op1 Mean±STD [Degree]	Post-op2 Mean±STD [Degree]
Pelvic			
RoM Pelvic Obliquity	4.5±0.2	5.0±0.8	3.3±0.5
RoM Pelvic Tilt	3.4±0.5	4.2±0.8	3.6±0.1
Mean Pelvic Tilt	9.9±0.4	12.3±0.8	11.1±1.1
RoM Pelvic Rotation	12.1±0.2	7.9±0.9	8.7±2.6
Hip			
Mean Hip Abd/Add	-4.6±0.1	-10.4±2.0	-6.0±0.4
Peak Hip Ext	-5.2±0.1	18.9±1.7	-8.3±0.9
Peak Hip Flex	33.3±2.1	34.9±1.3	31.7±1.2
RoM Hip Flex/Ext	38.5±2.0	15.9±3.0	40.1±0.2
RoM Hip Rotation	2.2±0.6	-12.6±0.8	7.7±1.1
Knee			
Mean at stance Knee Varus/Valgus	11.9±0.1	4.4±0.6	12.6±0.5
RoM Knee Flex/Ext	53.4±0.2	31.9±0.5	53.4±0.8
Peak at initial contact Knee Flex/Ext	12.0±0.6	17.9±1.8	6.5±0.2
Peak Knee Ext	7.6±0.5	15.9±0.6	2.5±1.6
Peak Knee Flex	61.0±0.2	47.8±0.4	55.9±0.7
Ankle			
RoM Ankle Dorsi/Plantar Flex	25.7±0.3	10.7±0.9	26.0±1.3
Peak at initial contact Ankle Dorsi/Plantar Flex	1.1±1.9	0.5±0.2	1.5±1.3
Peak Ankle Dorsi Flex	11.8±1.9	11.0±0.7	12.1±0.9
Peak Ankle Plantar Flek	-13.8±2.2	0.2±0.3	-13.9±2.2

RoM: Range of motion; Abd/Add: Abduction/Adduction; Flex/Ext: Flexion/Extension

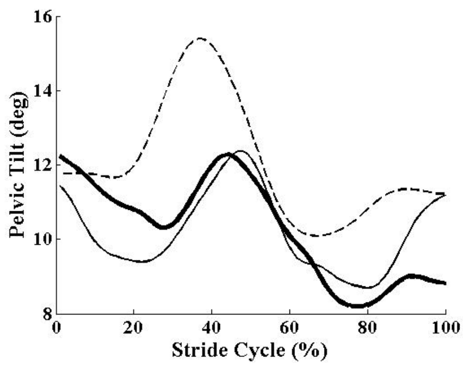
To improve the understanding of the influence of the operation on the gait characteristics, the overlapped kinematic gait parameter variations over one stride are given for pelvis (Fig 1), hip (Fig 2), knee (Fig 3a) and ankle joints (Fig 3b).



(a)



(b)



(c)

Figure 1. Comparison of the preoperative and postoperative pelvic angles computed from inverse kinematics. (a) pelvic obliqulity, (b) pelvic rotation, (c) pelvic tilt. Solid bold line: Pre-op, thin dashed line: post-op1, thin solid line: post-op2.

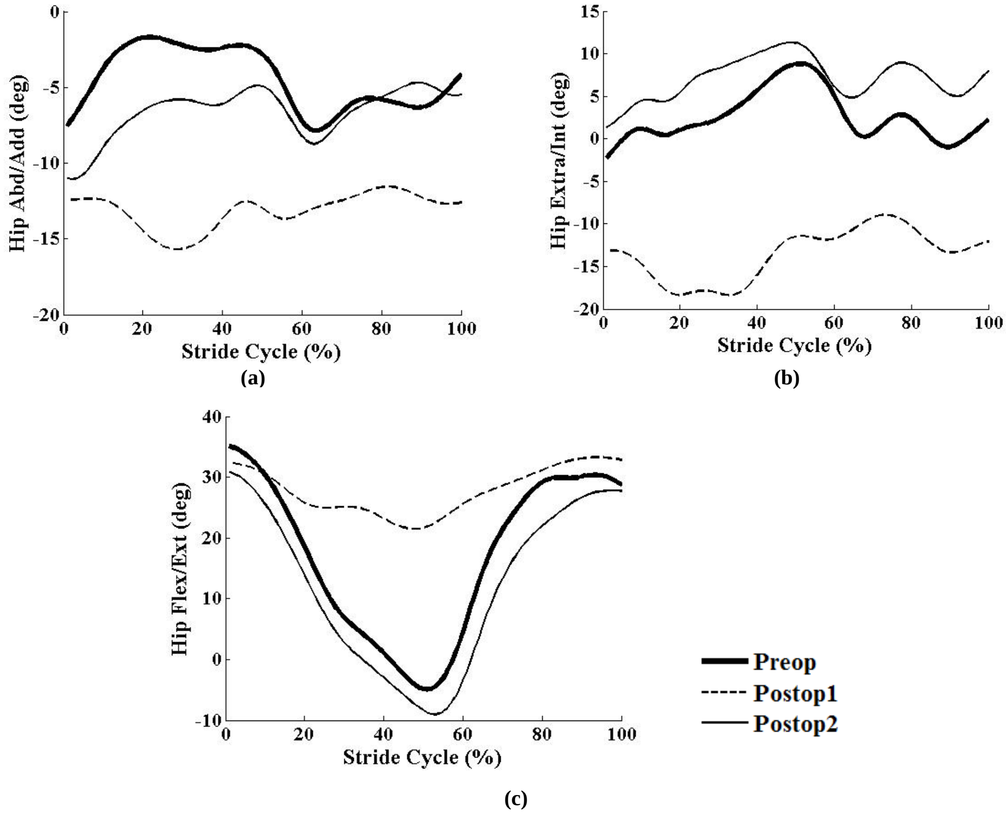


Figure 2. Comparison of the preoperative and postoperative hip angles computed from inverse kinematics. (a) hip abduction/adduction , (b) hip external/internal rotation, (c) hip flexion/extension.

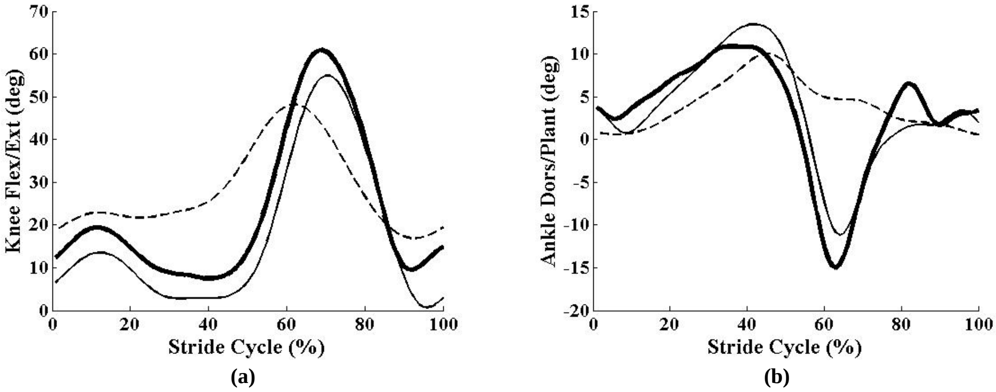


Figure 3. Comparison of the preoperative and postoperative joint angles computed from inverse kinematics. (a) knee flexion/extension, (b) ankle dorsi/plantar flexion. Solid bold line: Pre-op, thin dashed line: post-op1, thin solid line: post-op2.

Moment values for hip, knee and ankle joints are presented in Fig. 4.

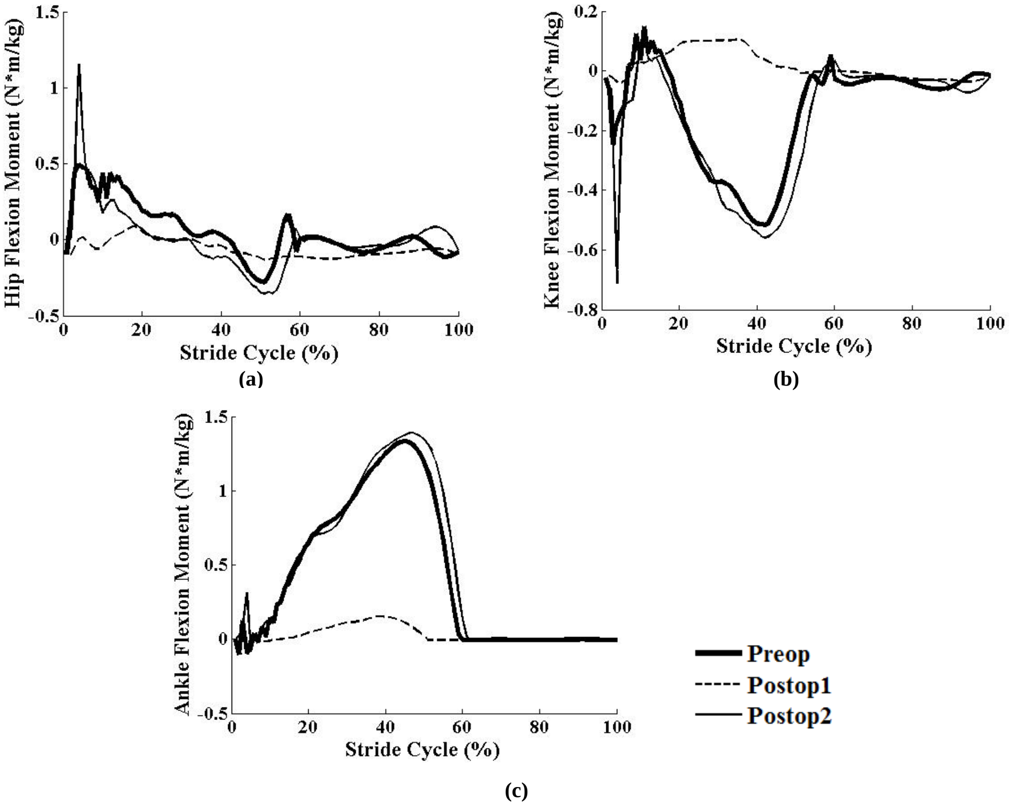


Figure 4. Comparison of the joint moments calculated for preoperative and postoperative periods for (a) hip flexion, (b) knee flexion, (c) ankle flexion movements.

Three muscles, which are the most susceptible to the grafting operation from iliac crest, were selected to evaluate the variation of length and force production capabilities that are expected to influenced by the grafting operation. These are the GMED, GMAX and ILIOP muscles. Length and force changes of the corresponding muscles over one stride were obtained using Opensim.

Comparison of the muscle length changes are given in Fig 5. It can be seen from the figure that length changes profiles predicted for post-op2 is quite similar to those for pre-op1.

Muscle forces obtained from SO are given in Fig. 6 and from CMC in Fig. 7. According to muscle force prediction results from SO, post-operative muscle forces are approaching to pre-operative characteristics while the recovery time increases, except ILIOP muscle. However, for the case of CMC technique used for the calculation of muscle forces, all forces obtained in post-op2 are closer to those in pre-op than the post-op1.

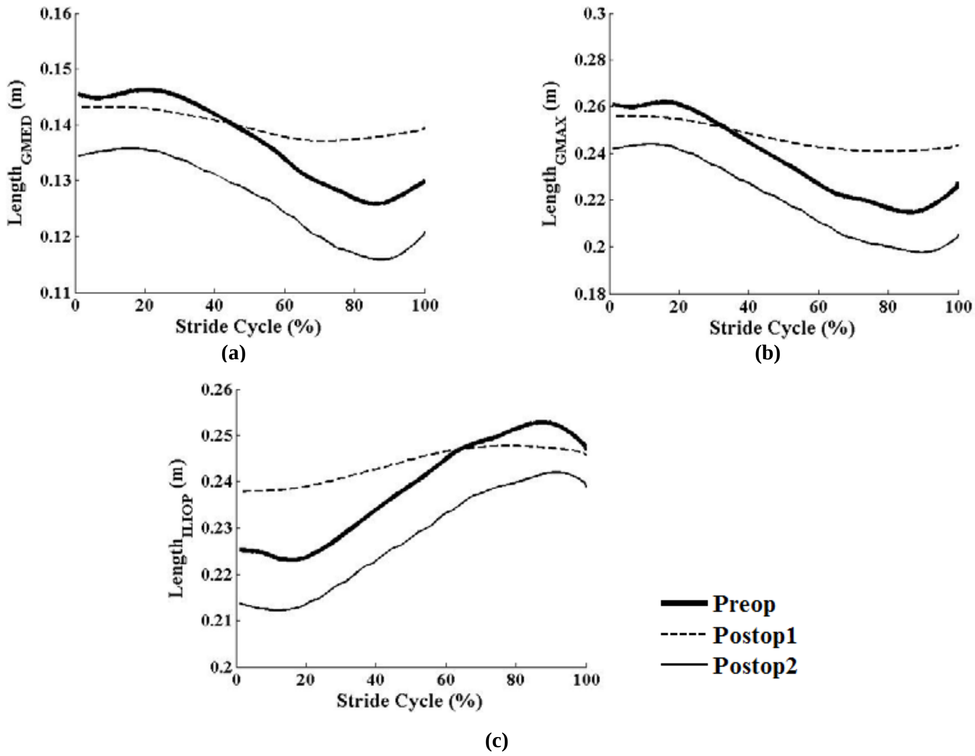


Figure 5. Comparison of the muscle length changes during the preoperative and postoperative stages. (a) Gluteus medius (GMED), (b) gluteus maximus (GMAX) and (c), iliopsoas (ILIOP).

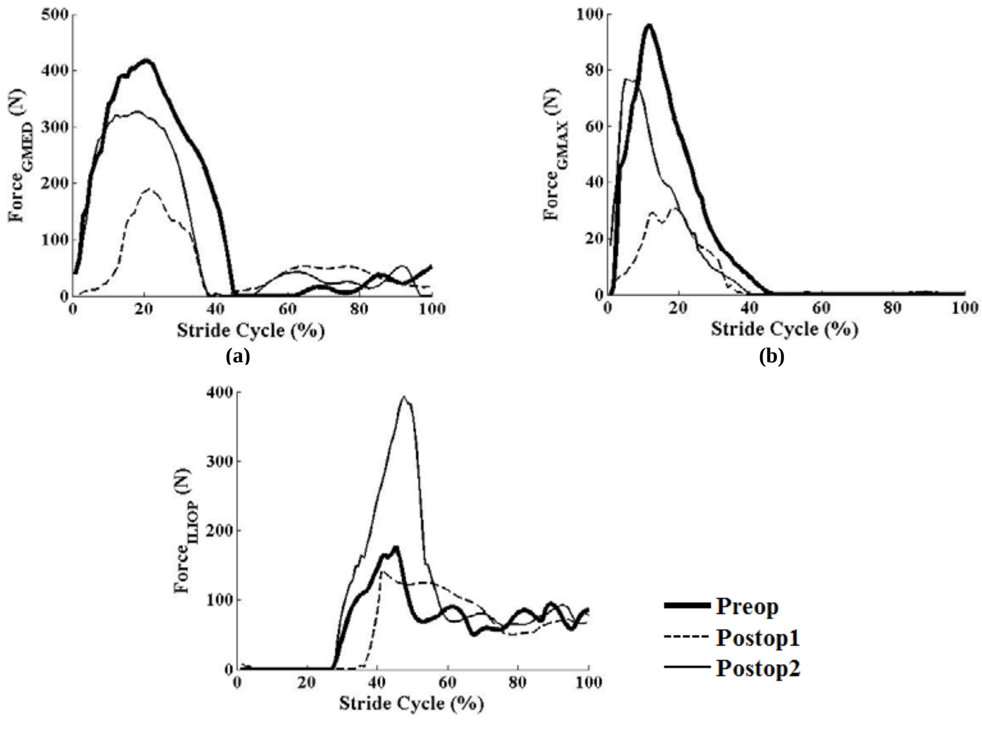


Figure 6. Comparison of the muscle forces computed from static optimization (SO) for preoperative and postoperative periods (a) GMED, (b) GMAX, (c) ILIOP.

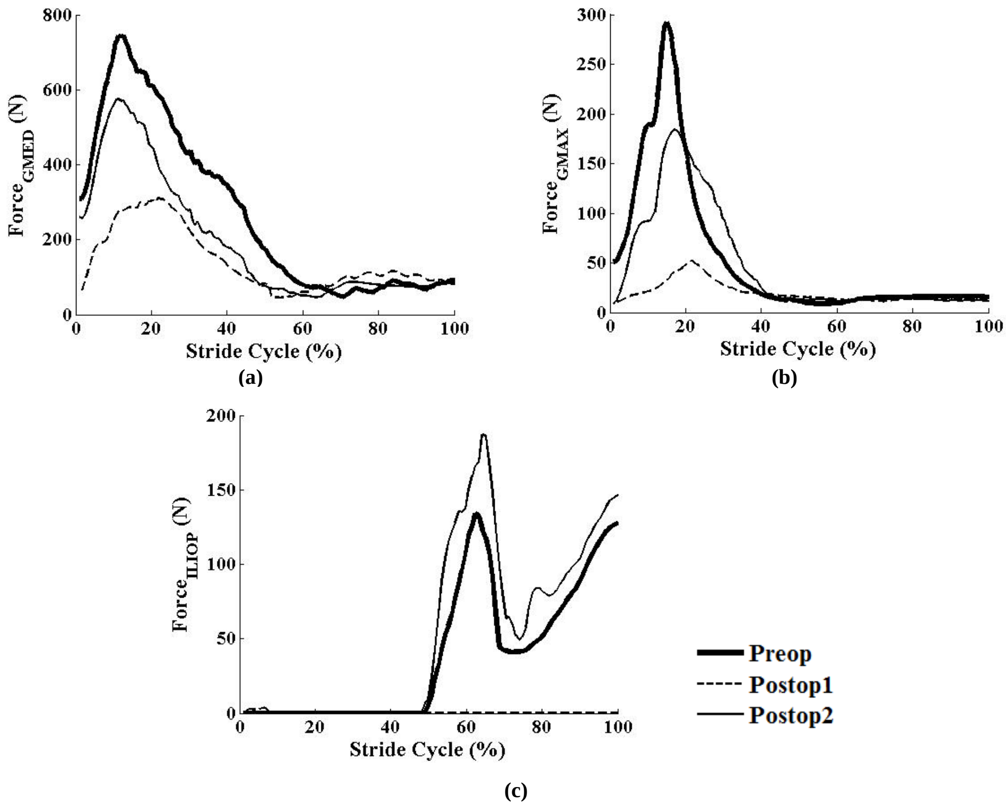


Figure 7. Comparison of the muscle forces computed from computed muscle control (CMC) technique for preoperative and postoperative periods (a) GMED, (b) GMAX, (c) ILIOP.

CONCLUSION

In this case study, it was aimed to compare the pre- and post-op gait characteristics of a patient subjected to the atrophic jaw augmentation. It was found that there are considerable differences in the spatio-temporal, kinematic and kinetic parameters between the pre- and post-op periods. It was also observed that while the treatment process progresses, patient begins to regain his normal gait characteristics from the second week after surgery. To have a definite conclusion about the time period of regaining the normal gait functions, it needs to include many subjects from the different groups of age and sex which is the ultimate goal of this ongoing study.

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