Learning curve of digital intraoral scanning – an in vivo study

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Abstract

Background The spread of digital technology in dentistry poses new challenges and goals for dentists. It is important to involve new methods and devices in university education. The aim of the present in vivo study was to determine the learning curve of IOS described by (1) scanning time and (2) image number (count of images made by intraoral scanner during scanning process).

Methods Ten dental students of Semmelweis University took part in the study. Dental students took digital study impressions using 3Shape Trios 3® (Copenhagen, Denmark) IOS device. Each student took 10 digital impressions on volunteers (for standardization the first and the last patients was the same for each student). The inclusion criteria of patients were full dentition (except missing third molar) and no prosthetic- restorative treatment. Digital impression taking was preceded by a lecture consisting of two parts: education and training. For standardization, the scanning device was calibrated before impression taking, followed by the registration of patient data. Digital impressions were taken of the upper and lower arches, and the bite was recorded according to the manufacturer's instructions. Total scanning time and image number of intraoral scanning were recorded.

Results The difference of scanning time between the first and the tenth digital impressions was significant (p=0.007). The average scanning time of first impressions was 23min 9sec, for tenth impressions it was 15min 28sec. The difference between scanning time of the first and the tenth impressions was 7min 41sec. The average image number of the first impressions was 1964.5, for the tenth impressions it was 1468.6. The difference between number of images of the first and the tenth impressions was 495,9. The curve of image number show decreasing tendency first, then has a trough around the sixth measurement, and rises.

Conclusion The learning curve of IOS can be described with scanning time and image number of digital impression. Scanning time decreases as result of practice. Shorter scanning times are accompanied by poorer coverage quality, the operator has to correct by adding extra images represented by the curve of image numbers which turning into increasing tendency after the sixth measurement.

Trial registration: The permission for this study was given by the University Ethics Committee of Semmelweis University (SE TUKEB number: 61/2016).

Background

The widespread use of digital technology is transforming our everyday life: computers and digital devices offer an easier, faster and more economical alternative way than conventional methods. In recent years, dentistry made progress with the integration of CAD/CAM (computer-aided design/computer-aided manufacturing) technology as well as many new tools and methods. After CAD/CAM technology was introduced, it did not take long for dental applications to emerge. Dr. Francois Duret was the first person who wrote about the application of CAD/CAM technology in dentistry. He created his first CAD/CAM restoration in 1983 and demonstrated his system in 1985 at the France Dental Association's international

congress. In 1989 at the Midwinter Meeting, Dr. Duret made a crown in four hours on stage. The impression was taken using an optical scanner and final restoration was designed on the computer screen and milled from a ceramic block with a numerically controlled milling machine. After that important milestone, several intraoral scanners were introduced [1]. In order to get involved in the direct digital workflow, the dentist must have an intraoral scanner [2]. Digital impression taking has benefits such as reduced gag reflex potential, decreased working time, no potential deformation of impression material or expansion of gypsum, real-time visualization, and easy repeatability [3–5]. Intraoral scanning also has some limitations: some studies states that conventional impressions is better solution for challenging prosthodontics (e.g. long-span restoration on multiple implants) [6–8], difficult bite registration (many systems does not permit registration of dynamic occlusion), scanning fees in closed systems (the user has to pay for performing the scanning data), costs (intraoral scanning systems are still expensive) [9]. Furthermore, these new methods have learning curve, dentists are required to spend time in learning to effectively use these devices. Learning is defined as “an enduring change in behavior or in the capacity to behave in a given fashion resulting from practice or other forms of experience” [10]. A learning curve is the representation of the rate of learning something over time or repeated experiences in a graph form [11]. In general medicine, concerning to introduce new technologies or techniques, several studies have determined the learning curve of users [12–14]. Most studies in the field of dentistry investigated the accuracy and effectiveness of intraoral scanners; however, little data is available about the proficiency of the person who is scanning [15–17]. Learning curve of intraoral scanning was investigated in many studies against conventional impression taking. The point of view in these studies was the perception of well-trained dentists and dental students. Students preferred the digital impression against conventional impression technique. Older clinicians were less passion about digital innovations of dentistry because they had a conventional method for impressions taking which used with good results for a long time [18, 19]. There have not been any standardized and randomized clinical studies about the learning curve of digital impression taking. For a practicing dentist, it is crucial to know the learning curve of taking digital impressions and the applicability of the scanner when considering the investment in a new system. The learning process is represented by the reduction of the time required for taking digital impressions and the change in the number of images of the virtual model.

The aim of the present in vivo study was to determine the learning curve of intraoral scanning described by (1) scanning time and (2) image number (count of images made by intraoral scanner during scanning process).

Methods

Presentation of education

The permission for this study was given by the University Ethics Committee of Semmelweis University (SE TUKEB number: 61/2016). Dental students from 6 and 10 semesters with no experience of digital impressions took part in this study. Students represented an average student attending to graduate

education of Semmelweis University. The study was preceded by education with theoretical and practical parts.

During the theoretical part of the education, a presentation was held by a dentist experienced in scanning, and an educational video (which was made by the research team) was viewed. The presentation was about the types, structure, operating principles, and indication areas of digital scanners. The Trios 3® intraoral scanner was introduced in detail, as it was used in the study. The video focused on the practical application of the scanner. In the video, the process of taking a digital impression was introduced step by step. This was followed by practical training. Each student took a digital study impression with a Trios 3® intraoral scanner of the lower and upper jaw models in an articulator, with occlusion recording (Fig. 1).

Participants

Ten dental students were involved in intraoral scanning in pairs assisting each other. Students had no previous experience with intraoral scanning. During scanning, supervision was granted by a dentist who was experienced in digital impression taking. Each student took 10 scans according to the following: they scanned eight different patients (who were also dental students), furthermore there was a patient who was scanned two times (first and last impression) by each examiner students. Participants' different individual factors such as saliva flow or mouth opening can affect the speed of digital scanning procedure. For standardization, the first and the last patient was the same person (a university employee). The scans were performed separately from each other. The whole data collection procedure was performed across from June 2016 to 2017 September. The inclusion criteria for patients were the following: full dentition (except the missing third molar), good oral hygiene, aged at least eighteen years, intact hard and soft tissue (no decay or teeth extraction socket), normocclusion (Angle I). The exclusion criteria were undergoing orthodontic treatment, dental implants, any prosthetic treatment (inlays/onlays or crowns), gingivitis or periodontitis.

Every scan was made by two dental students: one of them took the digital impression and the another assisted. The scanning student was on the right side and the assisting student was on the left side. The scans were performed with patients in a supine position. Every scan was performed with the help of a retractor (Optragate, Ivoclar Vivadent) to ensure the best accessibility. Dental light was turned off during scannings. (Fig. 2).

Intraoral scanner

As to the intraoral scanner, each time the same Trios 3® was used. Trios 3®, was introduced on the market in 2015. The third generation of Trios 3® intraoral scanner was available in both a pen grip design and handle grip. It can be incorporated into the dental unit or also available in a cart version with touch screen as well as USB version, which can be connected to a high- performance laptop. The software and hardware of Trios 3® have the capability to capture fully colored model. In this study according to a scanning protocol based on the manufacturer's instructions, students took digital impressions with the

USB pen grip version of Trios 3®, (Fig. 3) [9]. This scanner is a powder-free scanner which operates on the confocal principle with the video-recording method. Trios 3®, scanner is able to take HD pictures and determine the tooth shades. [9, 20]. Before starting to scan the scanner was calibrated using the respective calibration device. The software version 3Shape Trios Classic 1.3.4.6 was used.

Digital impression taking

At first, patient data and the digital order form were completed. Diagnostic scan was taken after selecting the “Study model” icon. Total impression taking time included scanning time required for complete digitalization of the upper and lower arches and bite registration on the right and left sides. Digitalization procedures were performed according to the manufacturer's instructions and previous education. For standardization, the scanning device was calibrated before impression taking. It was done using supplementary tips and the calibration box. The digitalization was started with the upper jaw, followed by the lower one. The scanning strategy on the upper arch is the following: occlusal surface followed by buccal surface and, finally, palatal surface. Scanning strategy on the lower jaw starts with the occlusal surface, then the lingual surface and, finally, the buccal surface [21]. Digitalization procedures were always started on the right second molar and ended on the left second molar. The next step was bite registration in intercuspidal position on both sides. During bite scan the scanner tip was inserted at molar region, the buccal side of the teeth and slowly moved in mesial direction. After the digitalization of the upper and lower arches, the virtual cast appeared on the screen. The virtual cast was accepted if all the surfaces were completely mapped, no crack lines were found, and the bite registration was successful (Fig. 4). If a crack line appeared on the virtual cast, the procedure was repeated. In case of missing data, additional images were taken. Irrelevant areas such as palatal soft tissue were removed.

Registered data

Scanning time was measured with a stopwatch. Time of data recording, processing time, scanning time of upper and lower jaws and time of bite registration were noted. Image numbers of upper and lower arches and bite registration were also recorded. Total scanning time was also measured from patients’ data recording step to sending the case to the lab step. Image number is the count of images made by intraoral scanner during scanning process. Number of images appeared automatically in the upper left corner of the screen after scanning. The present study focused on the total required scanning time and the total amount of images.

The importance of image number of virtual model

Working operation of intraoral scanner systems based on optical scanning techniques (visible light or amplified light beam). Trios 3® (3Shape, Copenhagen, Denmark) employs visible light beam for imaging and operates based on the real-time image capturing technology (ultrafast optical sectioning technique). The ultrafast optical sectioning technique utilizes up to 1000 3D images to create geometries based on real data [22]. Based on ultrafast optical sectioning Trios 3® makes digital models by taking pictures and stitching them to each other. The first picture is used as a reference and the others are connected to it

with some overlap. The greater the number of such overlaps can result more inaccurate virtual model. We should, therefore, try to create as few images as possible in obtaining a digital impression without any missing parts [23, 24].

Learning curve

A learning curve is the representation of the rate of learning something over time or repeated experiences in a graph form. We know many types of learning curves, but the classical type is a sigmoid shaped ascending curve starting from zero learning level. The curve can be divided into three parts. During the positive growing period, the learning speed of the testers is increasing constantly, followed by the middle section where the pace of learning is uniform. During the negative period, the learning speed of the testers decreases and, finally, the curve ends in a flat phase (Fig. 5).

If the number of measurements is represented on the x-axis and the y-axis represents the output, i.e. the required time or number of images, we get an inverse learning curve [10] (Fig. 6). In statistical evaluation, we can draw a reverse learning curve of the examined students from the point of view of required time and number of images.

Statistical analyses

Statistical evaluation was carried out using the Stata package to fit random-effects generalized least-squares regression models of outcome variables (required time and image count data) against the sequential number of measurements, a continuous explanatory variable analogous with learning stage. Relationship curvature was allowed by adding a squared term for measurement number if its effect was significant at $\alpha = 0.05$. Hausman's specification test was used to assess whether fitting a fixed-effects model was justified. Outcome variables were natural log-transformed to improve normality.

Results

From the 100 measurements, it can be seen that the average total impression taking time for the first measurement was 23 minutes 9 seconds, and 15 minutes 28 seconds for the tenth scanning. The difference between the first and the tenth scanning time (7 minutes 41 seconds) is significant ($p = 0.007$). The mean total image number for the first measurement was 1964.5; by the tenth measurement, it was 1468.6 (a difference of 495. 9). There is no consistent decline in average image number. For the required scanning time, the learning curve fitted on the measured data is consistent with the second part of a classic learning curve. (Fig. 7) As to image numbers, the curve has a trough around the sixth measurement, and then rises again. (Fig. 8) Within the limitation of our measurements, this curve is at the boundary of the middle and last thirds of the inverse learning curve.

Discussion

Since the introduction of CAD/CAM technology, techniques for its two initial steps, direct and indirect impression taking, have been studied by several researchers [25–27]. Increased interest in lab-connected intraoral scanners has induced more and more research. The accuracy and time efficiency of laboratory-based intraoral scanners, as well as the opinions of patients, dentists, students, and assistants, have been selected by many researchers as their topic [15, 20] many clinical studies, digital impression taking was carried out by well-trained dentists, i.e. they had used the examined scanners several times before [24, 27–30]. Nevertheless, it is not mentioned how and for how long this practice was carried out. Basically, the experience of scanner users determines the use of intraoral scanners [31, 32]. Many dentists refuse to use these new tools because of a long learning process. They believe that learning intraoral scanning will be just as difficult as the practice of traditional impression taking is for a student or a recently graduated dentist [33]. Investigating the learning process of how intraoral scanners are used is an important part of integrating them into everyday clinical practice. In the present study, our research group evaluated the effectiveness of intraoral scanning based on two parameters: scanning time and amount of image number. During digital impression taking the average scanning time was decreased because of practice. The average scanning time of tenth digital impression was 15 min 28 sec which is 7 min 41 sec less than the average scanning time of first impression. This time is remarkably close to other research group's results of the average measured scanning time. They also did not reach the flat phase of the curve while taking 10 digital impressions [34].

In our research, impressions were taken by dental students who had no previous experience with intraoral scanning. It allows the assessment of learning speed in digital dentistry objectively. On the other hand, dental students have openness for digital developments. Because of that fact their average scanning time could be less than experienced dentists'. For the required scanning time, the curve fitted on the measured data was located in the second part of a classic learning curve. Digital impression taking was preceded by a lecture consisting of two parts: education and training. In our research, the learning curve did not start from zero because of the lecture. The positive growing period was not shown in our curve. The learning curve showed a decreasing tendency, but the flat phase was not reached in this study [35]. For comparison, the average time for conventional (two-step silicone) impression of upper jaw is 7 min 30 sec (exclusive of preparation time e.g. tray selection) [36]. Another research group evaluated the total treatment time for conventional impression of maxillary and mandibular dental arches with polyether impression material (Impregnum, 3M ESPE) using the monophase impression technique. The last step of conventional technique was bite registration with polysiloxane bite registration material. The mean total treatment time of conventional technique was about 10 min 5 sec which was less than our time-result of intraoral scanning because in this case a well-trained clinician took the conventional impressions [37].

Image numbers have not yet been fully explored in the literature in this research field. As to image numbers, our curve has a trough around the sixth measurement, and then rises. Scanning speed was increased by practice but the operator made more mistakes during scanning. These missing areas had to be corrected by adding new images, as a result, the scanning speed decreased, but the image number increased. The average image number of tenth impression was 1468.6 for two arches and bite registration. Other research group from Shanghai Jiao Tong University School of Medicine conducted a

study in 2016. In their research after 96 digital impression taking of whole upper jaw, the average image number was 835. The digital impressions were made by a well-trained dentist from whole upper jaw it was the reason for the difference of results [36]. There is no correlation between image number acquisition and the accuracy of the digital impression. The number counter in scanner is made due to the risk of longer processing time, overheating of hardware or computer. It depends on the hardware specifications of the computer. For avoid the overheating of hardware in present research we use the Pod version of Trios 3® with the official laptop was sold with the scanner (HP OMEN Notebook PC 15, Windows 10, 1903 Version).

There are some limitations of this study. We used only one scanner 3Shape Trios 3®. It operates according to confocal laser technology, the data capture mode is video sequence [9]. There are many different types of scanners with different data capture principles which can result variant outcomes. Another limitation was the low number of scans. We made summa 100 digital impressions by 10 operators (10 scans by each examiner). In case of increasing the number of scanning the flat phase can reach. Furthermore, it could be interesting to compare the learning curve of students and experienced clinicians. Another limitation was the patient-related factors. Sun et al reported that saliva flow, movement of the tongue or the patient, and limited oral space had a strong influence on scanning speed [38, 39]. In our study, the first and the last patient was the same person for standardization of measurements. The other 8 patients were selected based on our inclusion and exclusion criteria which were detailed in the “Participants” paragraph.

Conclusions

The learning curve of intraoral scanning can be described with scanning time and image number of digital impression. Average scanning time was decreased because of practice (15 min 28 sec, the difference between the first and the last scanning was 7 min 41 sec). The image number first showed decreasing tendency and after sixth measurement it increased (average image number for the tenth intraoral scan was 1468.6 but there is no consistent decline in mean scanning picture). Scanning efficiency increased but shorter scanning times were accompanied by poorer coverage quality, the operator had to correct by adding extra images.

Within the limitations of this study the flat phase of the learning curve was not reached because ten digital impressions were not enough to reach the average scanning time/image number of an experienced user, therefore further measurements are necessary. This study evaluated progressive increase in scanning speed of digital impression taking with short period of training in digital impression method among dental students. Evaluating the operation of intraoral scanners is important for long term clinical application.

Abbreviations

CAD/CAM: Computer-Aided Design/Computer-Aided Manufacturing

Declarations

Ethics approval and consent to participate

The permission for this study was given by the University Ethics Committee of Semmelweis University (SE TUKEB number: 61/2016). Written informed consent was obtained from all participants.

Consent for publication

The patients and participants gave their written informed consent for participation in this study and publication of the gathered data (including pictures and digital impressions).

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

All authors made substantial contributions to the present study. DM and RI participated in digital impression taking before their graduation as a dental student. RI was a major contributor in writing the manuscript. JKG and CA acquired and analyzed the data. BJ and HP revised the manuscript before submission. All authors read and approved the final manuscript.

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Figures

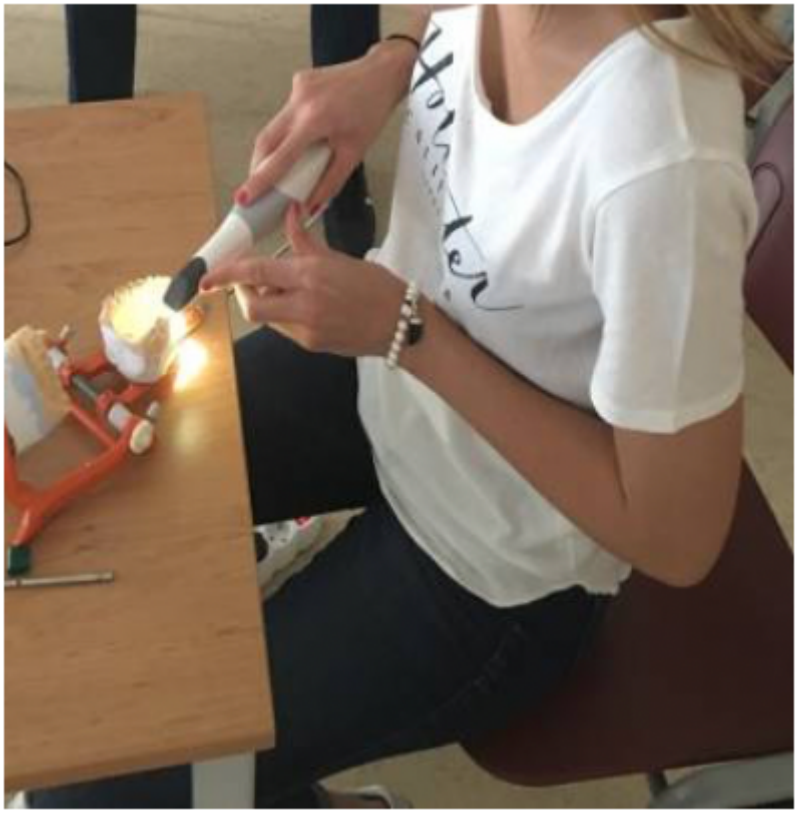

Figure 1

During practical training, students took digital impressions of the lower and upper jaws with a Trios 3® (3Shape, Copenhagen) intraoral scanner.

Figure 2

The scanning student was on the right side, the assisting student was on the left side. The patient was supine, and a retractor was used for better viewing.

Figure 3

Trios 3® (3Shape, Copenhagen, Denmark) intraoral scanner was used for digital impression taking.

Figure 4

The virtual model was accepted if every surface of every tooth was scanned and the bite registration was successful.

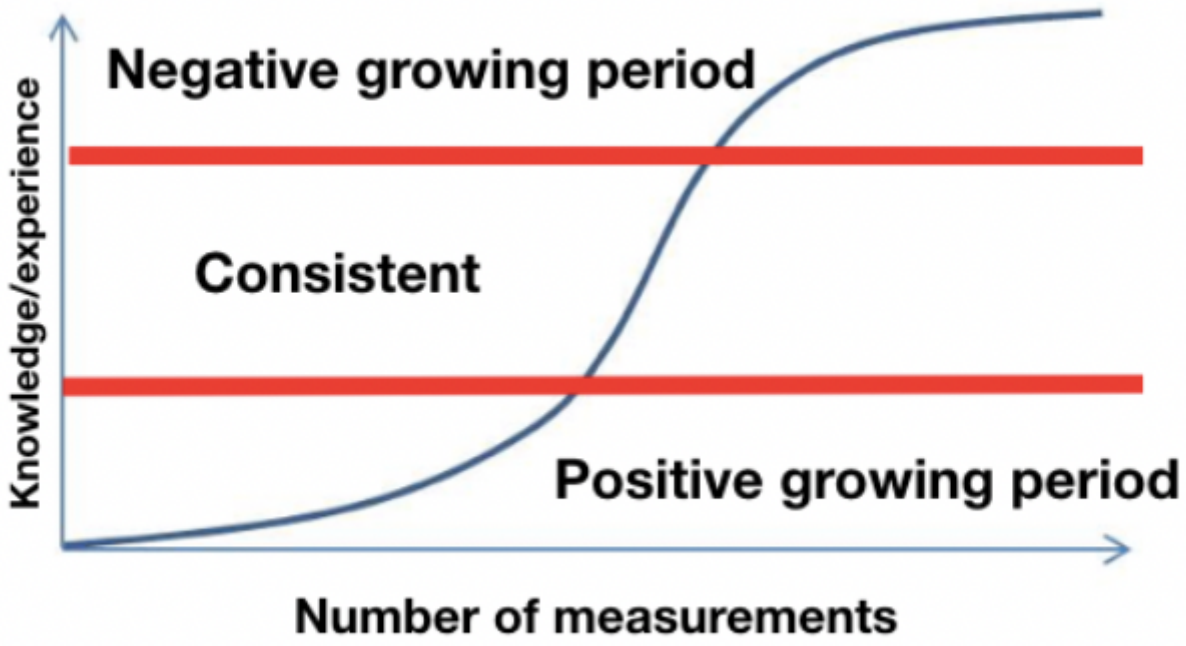

Figure 5

The classic-type learning curve. First part of the curve is the positive growing period when the speed of learning is continuously increasing. The second is the consistent part when the speed of learning does not change significantly. The negative growing period is the part when the speed of learning is progressively decreasing then the curve ends in a platou phase.

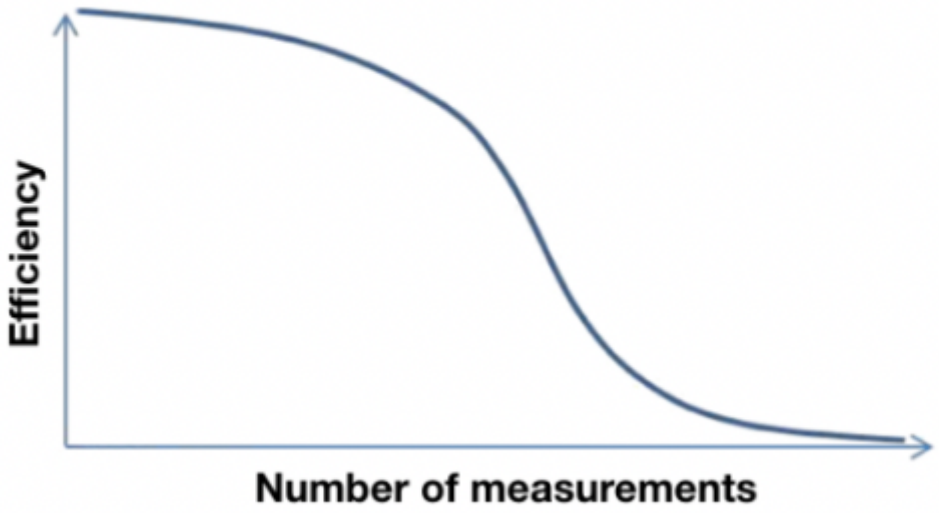

Figure 6

The inverse learning curve. If the number of measurements is represented on the x-axis and the y-axis represents the output, i.e. the required time or number of images, we get an inverse learning curve.

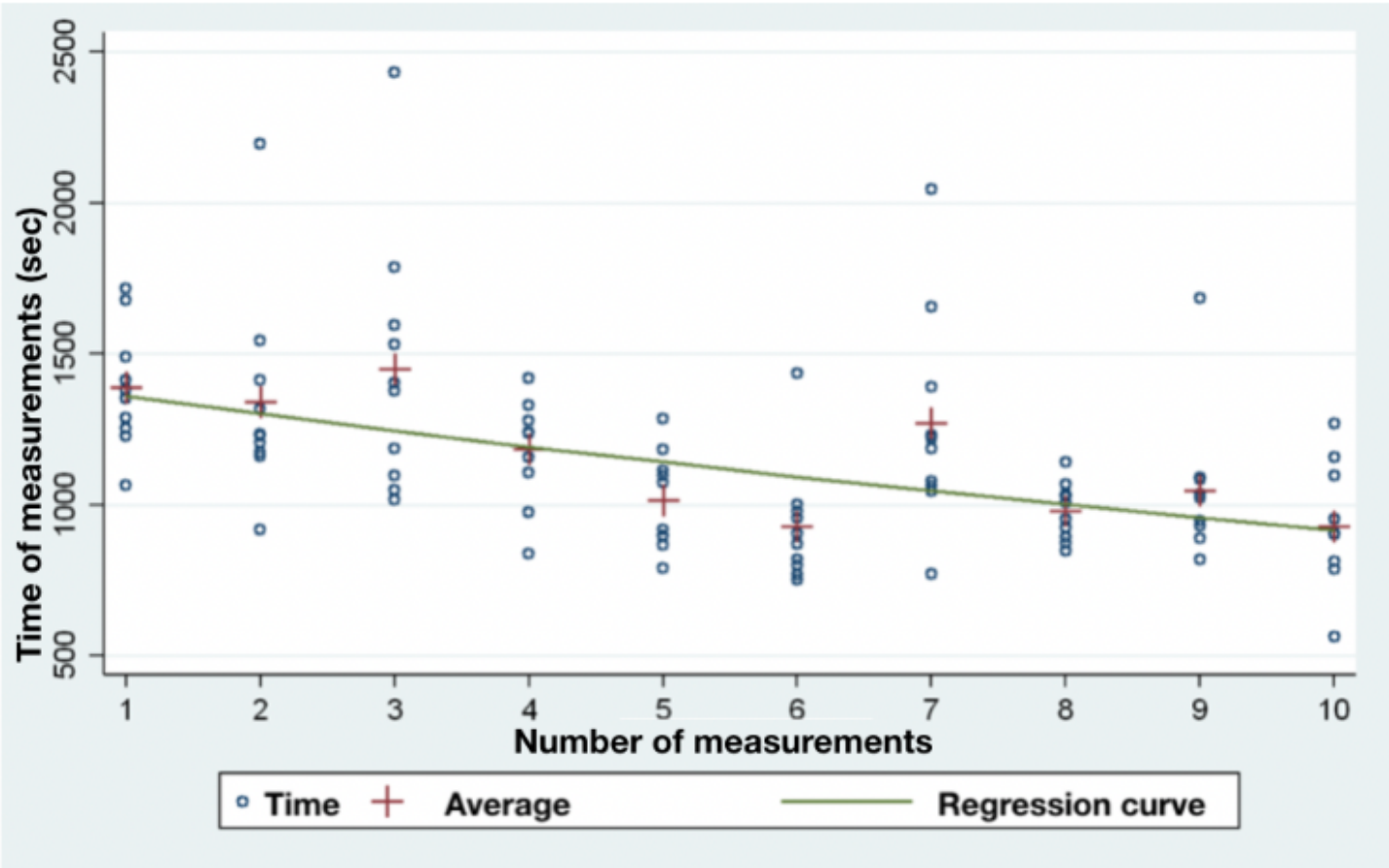

Figure 7

Regression curve of scanning time against measurement number. The curve is consistent with the second part of a classic learning curve.

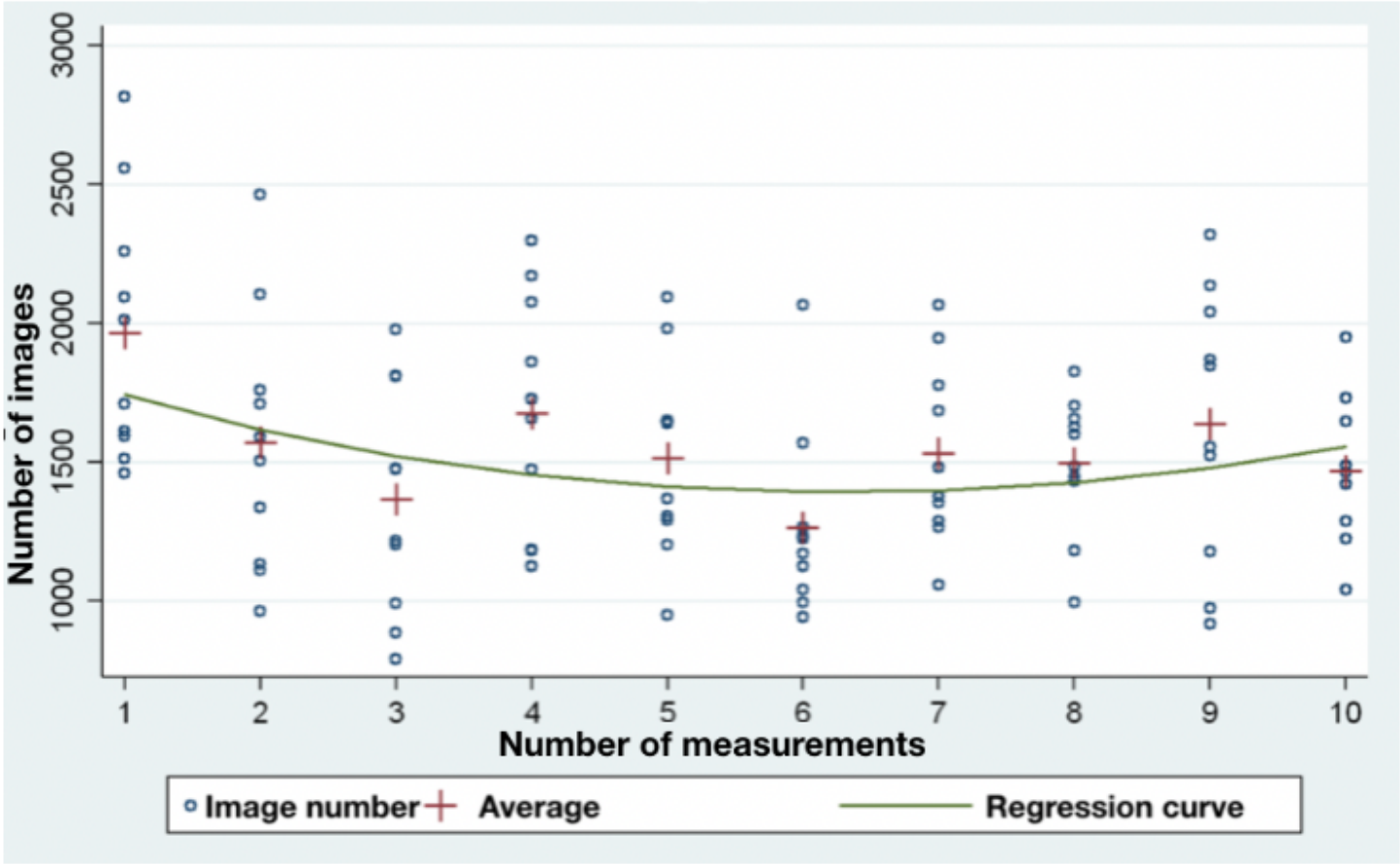

Figure 8

Regression curve of image count against measurement number. The curve has a trough around the sixth measurement, and then rises again.