Journal of the World Federation of Orthodontists 8 (2019) 68–72

Contents lists available at ScienceDirect

Journal of the World Federation of Orthodontists

journal homepage: www.jwfo.org

Research Article

In vivo and in vitro evaluation of the mechanical properties of orthodontic elastomeric ligatures

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ARTICLE INFO

Article history:
Received 10 October 2018
Accepted 26 January 2019
Available online 5 March 2019

Keywords:
Elastomeric ligatures
Tensile force
Tensile extension

ABSTRACT

Background: Elastomeric ligatures are polyurethane materials for securing arch wires into bracket slots. The mechanical properties of these ligatures deteriorate over time when exposed to different media prolonging treatment time.
Objectives: To determine the mechanical properties of different brands of elastomeric ligatures in three media.
Methodology: Experimental study assessing four brands of elastomeric ligatures: Dalton, American Orthodontics, Ormco, and Orthoclassics. A total of 120 ligatures per brand were divided equally and exposed to the oral environment, dry medium, and artificial saliva for 6 weeks. A digital force gauge was used to measure maximum tensile force and maximum tensile extension before and after exposure of elastomeric ligatures to the media. Normal distribution was assessed using Kolmogrov-Smirnoff test. Analysis of variance was used to compare mean maximum tensile force and mean maximum tensile extension between and within groups of elastomeric ligatures; level of significance was set at $P < 0.05$.
Results: Tensile properties of all brands of elastomeric ligatures were significantly different from one another in as-received condition. After 6 weeks in the different media, all the ligatures experienced a significant reduction in maximum tensile force $P < 0.0001$, whereas Ormco and American Orthodontics were the only brands with significant difference in maximum tensile extension in all the media $P < 0.0001$.
Conclusion: There were significant differences in mechanical properties of the elastomeric ligatures of the brands in as-received condition and after exposure to different media.

1. Introduction

A common method of securing arch wires into orthodontic brackets is the application of elastomeric ligatures (modules), which are synthetic elastics made from polyurethane materials. These materials are either thermosets or thermoplastics; however, their composition is a proprietary secret [1]. Some inherent mechanical properties exhibited by elastomeric ligatures, such as maximum tensile force and maximum tensile extension, are important to orthodontists in ensuring the efficiency of fixed orthodontic appliance. Tensile force is the maximal force required before rupture of a material. Elastomeric ligatures with high tensile force will produce more force, which may result in increased friction at the arch-wire bracket slot [2,3], whereas tensile extension is described as the length elastomeric ligature could be stretched to get to its tensile force [4]. Ligatures with a high tensile force are more difficult to break, thus engage the arch wire in the bracket slot for a longer period [1]. The mechanical properties of elastomeric ligatures are altered following their use [1,5]. Some factors that may alter the mechanical properties of elastomeric ligatures include chemicals from saliva [1], oral fluoride rinses [6], and variations in oral temperature due to ingestion of hot or cold drinks and foods. Studies have shown that there is a rapid decline in the force levels of elastomeric ligatures when exposed to the oral environment or in vitro media [7,8]. These may alter their role in securing the arch

Funding: The authors have not declared a specific grant for this research from any funding agency in the public, commercial or not-for-profit sectors.
Competing interests: Authors have completed and submitted the ICMJE Form for Disclosure of potential conflicts of interest. None declared.
Provenance and peer review Non-commissioned and externally peer reviewed.
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2212-4438/$ – see front matter © 2019 World Federation of Orthodontists.
https://doi.org/10.1016/j.ejwf.2019.01.004

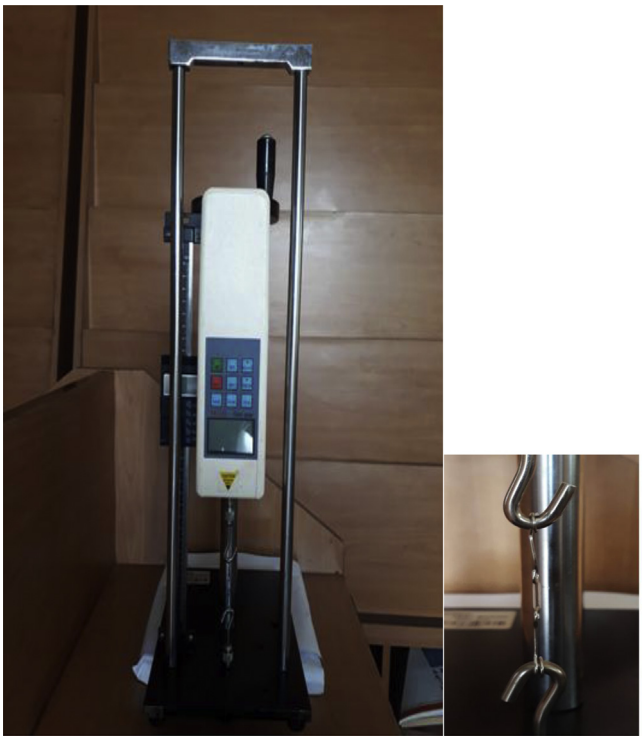

Fig. 1. Digital force gauge on a manual test stand.

wire into the bracket slot leading to reduced effectiveness during fixed appliance therapy. Previous studies have focused on the effect of oral rinses [9], artificial saliva [1], and distilled water [7] on force degradation of orthodontic elastics and elastic chains, which are similar products made from elastomerics; however, reports from studies on the change in mechanical properties of elastomeric ligatures, such as tensile force and tensile extension, are scarce. More so, the few available studies in literature were performed in simulated oral environments, and these in vitro research methodologies may not effectively represent the multifaceted intraoral environment. The aim of this study was to assess the tensile force and tensile extension of different brands of elastomeric ligatures before and after 6 weeks in dry medium, artificial saliva, and oral environment.

2. Material and methods

This study was conducted at the orthodontic laboratory and clinic and microbiology laboratory of University College Hospital, Ibadan, Nigeria. Four brands of elastomeric ligatures, from Dalton (Orthodentalusa, Weston, FL), American Orthodontics (Sheboygan, WI), Ormco (Ormco Corporation West Collins, Orange, CA), and Orthoclassics (Alpha Dr. Minnville, OR), were assessed in this study. A digital force gauge Fig. 1 (Chatillon DFS II Series; AMETEK Inc., Berwyn, PA) with accuracy to 0.01 (0.01%) was used to measure maximum tensile force and maximum tensile extension in as-received condition on a test stand. The ligatures were stored in the refrigerator at 4°C during the study. Ethical approval was obtained from the University of Ibadan/University College Hospital ethical review committee before commencement of the study with approval number UI/EC/14/0255.

2.1. In vitro assessment of elastomeric ligatures

Typodont models were used for the laboratory aspect of the study. The typodonts were grouped based on the media to which they were exposed (group 1: dry medium, and group 2: artificial saliva). Eight typodonts were placed in each group and a total of 16 typodonts for both groups. Each typodont model was bonded with central incisor, lateral incisor, canine, first premolar, and second premolar brackets. In all, 20 brackets were placed on each typodont. Two typodonts were picked from each group and 0.017 × 0.025 stainless steel rectangular wires were secured on the bracket slots of the typodont with a brand of elastomeric ligatures for standardization. The same procedure was repeated for all typodonts. The ligatures were placed carefully not to damage the structure with a pair of mosquito forceps using the conventional method (O-ring tie). Group 1 typodonts were placed directly in an incubator at 37°C to represent dry medium, whereas group 2 typodonts were placed in artificial saliva bath and the bath placed in an incubator at 37°C. The artificial saliva used in this study was Fusayama/Meyer artificial saliva (Pickering Laboratories, Inc., Mountain View, CA), composed of water, distilled water, deionized water (97%–100%), potassium chloride (<0.1%), urea (<0.5%), sodium chloride (<0.1%), sodium phosphate monobasic dehydrate (<0.1%), calcium chloride dehydrate, sodium sulfide nonahydrate (≤0.0005%), pH 4.9 ± 0.10.

The experimental ligatures were retrieved with a dental probe from the typodonts and assessed for change in their mechanical properties at the orthodontic laboratory at different timed intervals of 1 day, 1 week, 3 weeks, and 6 weeks. The elastomeric ligature was attached to the U-shaped loop on the force gauge and also to the U-shaped loop attached to the flat base of the manual test stand (Fig. 1). This was modified from a protocol adopted by Ahrari et al [1]. As the manual handle of the test stand is turned, the U-shaped loops to which elastomeric ligatures were attached were pulled apart, thereby stretching the ligatures until they were broken. The tensile force of the ligatures in Newton (N) was displayed on the screen of the digital force gauge, whereas tensile extension (mm) was displayed on the screen of the digital ruler marker. Values for tensile force and tensile extension were recorded in the data collection form.

2.2. In vivo assessment of elastomeric ligatures

Informed consent and verbal assent were obtained from 20 patients between ages 13 and 19 years at the finishing stage of fixed straight wire appliance. Anterior segment (central, lateral incisors) in all quadrants was chosen for the study so as to eliminate variation in plaque accumulation on the posterior segmental teeth, which could affect the study outcome.

Two elastomeric ligatures of the same brand were placed per quadrant (central and lateral incisors). The elastomeric ligatures were placed on the brackets using the conventional method (O-ring tie). Participants were instructed to adhere to proper brushing techniques, brush twice daily, and also to refrain from using oral

Table 1
Comparison of mean mechanical properties of brands of elastomeric ligatures in as-received condition

Tensile properties	Dalton mean (SD)	American orthodontics mean (SD)	Ormco mean (SD)	Ortho classics mean (SD)	F	*P*
Tensile force (N)	23.6 (2.0)	24.9 (1.6)	22.3 (1.0)	28.4 (1.6)	102.7	<0.001[a]
Tensile extension (mm)	10.2 (1.5)	12.6 (1.1)	14.4 (1.1)	14.2 (0.9)	93.1	<0.001[a]

F value, analysis of variance statistic value; SD, standard deviation.
[a] *P* value significant at <0.05.

Table 2
Comparison of mean maximum tensile force (N) of brands of elastomeric ligatures after exposure in various media at different time intervals as against as-received condition

Brands of ligatures in different media	As received mean (SD)	1 d mean (SD)	1 wk mean (SD)	3 wk mean (SD)	6 wk mean (SD)	F	*P*
Dalton							
Dry medium	23.6 (2.0)	23.0 (2.3)	20.4 (2.1)	20.2 (0.9)	20.8 (2.7)	23.9	<0.000[a]
Artificial saliva	23.6 (2.0)	20.4 (1.9)	18.6 (2.5)	19.0 (2.2)	19.2 (2.0)	31.9	<0.000[a]
Oral environment	23.6 (2.0)	18.1 (2.8)	18.0 (3.6)	18.2 (3.5)	16.9 (3.1)	26.9	<0.000[a]
F value		61.6	32.65	35.83	45.63		
P value		<0.001[a]	0.001[a]	0.001[a]	<0.001[a]		
American Orthodontics							
Dry medium	24.9 (1.6)	21.0 (2.5)	20.9 (2.6)	23.7 (1.1)	24.0 (2.1)	21.23	<0.000[a]
Artificial saliva	24.9 (1.6)	23.0 (1.6)	21.7 (3.7)	23.1 (2.4)	23.8 (1.8)	9.30	0.003[a]
Oral environment	24.9 (1.6)	22.6 (2.5)	21.6 (2.6)	21.5 (2.3)	20.6 (2.7)	17.5	0.02[a]
F value		21.41	15.41	6.66	26.89		
P value		0.001[a]	0.001[a]	0.001[a]	< 0.001[a]		
Ormco							
Dry medium	22.3 (1.0)	21.0 (1.8)	21.0 (1.9)	20.7 (2.2)	20.5 (2.3)	4.6	0.002[a]
Artificial saliva	22.3 (1.0)	21.0 (2.0)	20.5 (1.7)	20.9 (2.1)	20.9 (1.6)	5.6	0.000[a]
Oral environment	22.3 (1.0)	20.4 (2.3)	20.0 (2.3)	20.4 (2.6)	20.0 (2.2)	7.1	0.000[a]
F value		1.02	1.43	0.30	1.16		
P value		0.38	0.24	0.83	0.33		
Orthoclassics							
Dry medium	28.4 (1.6)	25.5 (2.0)	24.2 (1.6)	24.9 (1.9)	25.0 (2.3)	2.92	0.000[a]
Artificial saliva	28.4 (1.6)	25.1 (2.8)	24.2 (2.7)	24.3 (2.5)	24.3 (1.9)	4.00	0.000[a]
Oral environment	28.4 (1.6)	23.8 (3.1)	23.6 (3.3)	23.3 (3.3)	22.8 (3.2)	0.69	0000[a]
F value		22.94	30.63	28.27	37.47		
P value		0.001[a]	0.001[a]	< 0.001[a]	0.001[a]		

F value, analysis of variance statistic value; SD, standard deviation.
[a] *P* value significant at <0.05.

hygiene products such as mouth rinses during the study, as these could affect the study outcome.

A digital force gauge on a manual test stand was used to measure maximum tensile force and maximum tensile extension at different timed intervals of as-received, day 1, week 1, week 3, and week 6 for all the different media.

2.3. Data analysis

Data analysis was done using Statistical Package for Social Sciences, Version 23 (IBM Corp., Chicago IL). Normal distribution was assessed using Kolmogrov-Smirnoff test. Analysis of variance was used to compare the tensile force and tensile extension between and within groups of elastomeric ligatures and the results are presented in Tables 1–3. Level of significance was set at $P < 0.05$.

3. Results

The mean values with standard deviations of the elastomeric ligatures are as follows: Orthoclassics brand had the highest mean maximum tensile force (28.4 ± 1.6 N), whereas Ormco had the highest mean maximum tensile extension (14.4 ± 1.1 mm) and the lowest mean maximum tensile force (22.3 ± 1.0 mm) and Dalton brand of elastomeric ligatures had the lowest mean maximum

Table 3
Comparison of mean tensile extension (mm) of brands of elastomeric ligatures after exposure in various media at different time intervals as against as-received condition

Brands of ligatures in different media	As-received mean (SD)	1 d mean (SD)	1 wk mean (SD)	3 wk mean (SD)	6 wk mean (SD)	F Value	*P*
Dalton							
Dry medium	10.2 (1.5)	12.5 (1.7)	13.2 (1.8)	10.6 (1.3)	11.3 (2.7)	35.7	<0.001[a]
Artificial saliva	10.2 (1.5)	10.6 (1.3)	11.0 (1.9)	11.4 (1.7)	12.2 (2.0)	5.44	0.001[a]
Oral environment	10.2 (1.5)	11.3 (2.0)	10.5 (1.9)	11.4 (2.1)	10.6 (2.1)	2.23	0.09
F value		5.52	57.17	5.34	6.21		
P value		0.001[a]	<0.001[a]	0.002[a]	0.001[a]		
American Orthodontics							
Dry medium	12.6 (1.1)	11.7 (1.4)	11.9 (1.3)	11.9 (0.5)	10.5 (1.7)	63.09	<0.001[a]
Artificial saliva	12.6 (1.1)	12.8 (1.5)	13.0 (1.8)	13.1 (1.5)	12.6 (2.2)	5.59	0.001[a]
Oral environment	12.6 (1.1)	13.5 (1.8)	13.0 (1.6)	13.1 (2.0)	12.4 (1.5)	2.32	0.08
F value		2.39	27.70	6.87	6.41		
P value		0.07	<0.001[a]	<0.001[a]	0.001[a]		
Ormco							
Dry medium	14.4 (1.1)	12.6 (1.7)	12.6 (1.2)	13.0 (1.5)	11.9 (0.8)	5.93	0.001[a]
Artificial saliva	14.4 (1.1)	12.6 (1.3)	12.6 (1.4)	12.5 (1.5)	11.6 (1.2)	4.96	0.003[a]
Oral environment	14.4 (1.1)	13.3 (1.8)	12.4 (1.5)	12.3 (1.7)	12.5 (1.7)	4.34	0.006[a]
F value		6.37	13.96	9.05	27.75		
P value		0.001[a]	0.001[a]	0.001[a]	0.001[a]		
Orthoclassics							
Dry medium	14.2 (0.9)	13.2 (1.3)	14.0 (1.1)	15.0 (3.0)	16.3 (2.6)	92.57	<0.001[a]
Artificial saliva	14.2 (0.9)	14.3 (1.6)	12.0 (1.3)	12.5 (1.5)	12.9 (1.3)	16.37	<0.001[a]
Oral environment	14.2 (0.9)	13.8 (1.7)	13.8 (1.7)	12.5 (2.7)	12.3 (2.4)	4.33	0.006[a]
F value		20.92	79.47	30.30	42.93		
P value		<0.001[a]	<0.001[a]	<0.001[a]	<0.001[a]		

F value, analysis of variance statistic value; SD, standard deviation.
[a] *P* value significant at <0.05.

tensile extension (10.2 ± 1.5 mm). There was significant reduction in mean maximum tensile force of Dalton elastomeric ligatures after 6 weeks in the dry medium (20.8 ± 2.7 N), artificial saliva (19.2 ± 2.0 N) and oral environment (16.9 ± 3.1 N) ($P < 0.05$). Also, there was a statistically significant reduction in mean maximum tensile force of Dalton brand in the different media at all timed intervals ($P < 0.001$).

American Orthodontics elastomeric ligatures also depicted a significant reduction in mean maximum tensile force in all media at the end of 6 weeks (dry medium: 24.0 ± 2.1 N, artificial saliva: 23.8 ± 1.8 N, and oral environment: 20.6 ± 2.7 N) ($P < 0.05$). Similarly, when mean maximum tensile force of American Orthodontics ligatures exposed to dry medium, artificial saliva and oral environment was compared at all timed intervals with as-received condition, a statistically significant reduction was observed in all the media ($P < 0.05$; Table 1). Comparing the reduction in mean maximum tensile force at intervals of assessment in the different media with as-received Orthoclassics ligatures, a significant change was also reported for all timed-intervals ($P < 0.05$). Ormco brand of elastomeric ligatures showed no significant change in mean maximum tensile force in the different media when compared with as-received condition.

The variations in mean tensile extension of Dalton elastomeric ligatures with time was statistically significant only in dry medium ($P < 0.001$) and artificial saliva ($P < 0.001$) at the end of 6 weeks (Table 2). Concerning American Orthodontics elastomeric ligatures, there was a statistically significant decrease in mean maximum tensile extension over time in dry medium ($P < 0.001$) and artificial saliva ($P = 0.001$), whereas the effect of time on Ormco elastomeric ligatures mean maximum tensile extension, depicted significant reduction in values in all the media (dry medium [11.9 ± 0.8 mm], artificial saliva [11.6 ± 1.2 mm], oral environment [12.5 ± 1.7 mm]) ($P < 0.05$). Similarly, the mean maximum tensile extension of Orthoclassics ligatures in various media was significantly different in the various media (dry medium, $P < 0.001$; artificial saliva, $P < 0.001$; oral environment, $P = 0.006$) at the end of 6 weeks.

4. Discussion

This study aimed to report mechanical properties of some currently marketed elastomeric ligatures. There were significant differences in the mechanical properties of all brands of ligatures assessed in as-received condition and post insertion in the different media. After 6 weeks post insertion in the different media, the dry medium showed a decrease of 3.9% to 11.9% in maximum tensile force of all brands elastomeric ligatures assessed. A reduction of 6.4% to 18.1% and 10% to 33% in maximum tensile force was observed in artificial saliva and oral environment respectively, whereas maximum tensile extension increased in the Dalton brand of elastomeric ligatures and decreased in all others (Orthoclassics, Ormco and American Orthodontics).

Ahrari et al. [1], in an experimental laboratory-based study, assessed tensile properties of five brands of elastomeric ligatures (American Orthodontics, GAC (GAC International, Bohenia, NY), All-star (Columbia, IN), Dentaurum (Laughorne, PA) and Ortho technology (Luzt, FL) in both as-received and after 28 days in a simulated oral environment. They reported significant differences in mechanical properties of all brands of elastomeric ligatures tested. This observation was similar to that obtained in this study. More so, the mean maximum tensile force of 22.6 ± 1.4 N for American Orthodontic ligature was comparable to that observed in this study. Lam et al. [10] investigated the maximum tensile force and tensile extension of seven replicates of five ligatures from two orthodontic companies using an ex vivo assembly. In that study [10], the authors reported a mean maximum tensile force of 19.2 N, which was similar to the result seen in the present study. However, Lam et al. [10] observed a mean tensile extension of 6.9 ± 0.5 mm for Ormco in as-received condition, which was lower than what was obtained (14.4 ± 1.1 mm) in this study. Ahrari et al. [1] also reported a lower value of 11.9 ± 0.5 mm for tensile extension of American Orthodontics ligatures compared with this study. The observed variations in mean maximum tensile extension of elastomeric ligatures could be attributed to the differences in research methodology in the previously mentioned studies, as ligatures were subjected to a cross head speed of 25 mm/min [10] and 5 mm/min [1], respectively, whereas in the present study, tensile extension was measured with digital force gauge on manual test stand. This may cause variations in results, as tensile properties are sensitive to speed of extension.

More so, lower values of mean maximum tensile force for all brands were consistently observed in the oral environment at all timed intervals, which was comparable to a study by Kuster et al. [11] who examined two brands of elastic chains (Alastic Unitek Chains, Monrovia, CA) and Power (Ormco, Orange, CA) for force development in vivo and in vitro assembly. They reported a more extensive force loss during intraoral use, although their study was conducted on elastomeric chains; both materials were made from polyurethane.

A study on intraoral aging of elastomeric ligatures by Guimaraes et al. [12] detected significant changes in the maximum tensile force of elastomeric ligatures after normal intraoral use. These changes in tensile force of elastomeric ligatures was attributed to a process known as hydrolysis, in which secondary bonds in the molecules of elastomeric materials were broken down, resulting in relaxation and eventual reduction in force [13]. Some factors that enhance hydrolysis present in the oral environment, such as intermittent stress [14] and pH [15], may partly explain the reason for the greater loss in tensile force of elastomeric ligatures exposed to oral environment when compared with in vitro media.

Comparing the in vitro aspect of this study, a greater reduction in mean maximum tensile force was observed in artificial saliva at the end of 6 weeks when compared with dry medium. This result is similar to that obtained in studies conducted by Al-Kassar [16] and Ash and Nikolai [17] in which the force loss of elastomeric chains and elastomeric ligatures in different environments, at different intervals was greater in artificial saliva when compared with dry medium. Similarly, Evangelista et al. [9] reported that the aqueous component in the artificial saliva might plasticize or cause degradation of elastomers, thereby leading to a greater loss in wet than dry medium.

There was a gradual decrease in mean tensile force post insertion in the dry medium, artificial saliva, and oral environment over time. However, there were intervals of small increments for some elastomeric ligatures in all media. The observed increments were similar to those obtained in other studies [5,13] on elastomeric ligatures and chains, in which reports of significant decrease in tensile force and similar small increases at some time intervals were noticed. Singh et al. [18] attributed these increases to variations in manufacturing process, or different morphological and dimensional characteristics of elastomeric ligatures, but observed variations from this study may be due to the use of manual test stand.

With respect to maximum tensile extension, after immersion in the test media, all elastomeric ligatures decreased at some point and increased at other time intervals. This finding was inconsistent with the result obtained from Ahrari et al. [1], who observed an overall decrease in tensile extension, and contrary to that of Lam et al. [10], who reported a general increase in tensile extension throughout their study period. The reasons for these observed differences in mean tensile extension of elastomeric ligatures in

different studies are not immediately apparent, but may be partly due to the differences in methodology.

However, the study is not devoid of its limitations. The expiry dates of the brands of elastomeric ligatures tested were not stated on the products, but were subsequently stored in a refrigerator at 4°C after initial assessments to preserve their mechanical properties. The mechanical properties of the elastomeric ligatures might change during the period of removal from typodonts and measurement with the force gauge. Most probably, these changes will be similar for the four brands. In addition, the force gauge was mounted on a test stand. The period of this study was 6 weeks; however, a study with longer interval is suggested to determine the residual maximum tensile force and tensile extension beyond the study duration.

5. Conclusion

There were significant differences in the tensile strength, extension to tensile strength of different brands of elastomeric ligatures in as-received condition; therefore, different ligatures may have optimal performance at different stages of fixed appliance therapy. All the brands of elastomeric ligatures showed statistically significant changes in their tensile and extension to tensile force post insertion in the three different media at all timed intervals.

Acknowledgments

This is to acknowledge the following for contributing to the study: Dr Obioma C. Uchendu, Department of Community Medicine, University of Ibadan, and Dr James A. Adegoke, Department of Physics, University of Ibadan, Nigeria.

The views expressed in this article are entirely the authors' and does not represent the official position of the institution. The authors declare no conflict of interest as the study was entirely self-funded.

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