Distribution Statement

Distribution A: Public Release.

**UNIFORMED SERVICES UNIVERSITY OF THE HEALTH SCIENCES**
POSTGRADUATE DENTAL COLLEGE
NAVAL POSTGRADUATE DENTAL SCHOOL
8955 WOOD ROAD
BETHESDA, MARYLAND 20889

THESIS APPROVAL PAGE FOR MASTER OF SCIENCE IN ORAL BIOLOGY

Title of Thesis: Occlusal accuracy of milled denture teeth with different morphologies

Name of Candidate: Tuan N. Tran
Master of Science Degree
June 01, 2021

THESIS/MANUSCRIPT APPROVED: DATE:

6/17/21

Jeffrey J. Kim
RESEARCH DEPARTMENT, NAVAL POSTGRADUATE DENTAL SCHOOL
Committee Chairperson

6/21/21

Anton Petrich
PROSTHODONTICS DEPARTMENT, NAVAL POSTGRADUATE DENTAL SCHOOL
Committee Member

6/14/21

Stacy L. Yu
PROSTHODONTICS DEPARTMENT, NAVAL POSTGRADUATE DENTAL SCHOOL
Committee Member

# OCCLUSAL ACCURACY OF MILLED DENTURE TEETH WITH DIFFERENT MORPHOLOGIES

by

Tuan Tran
Lieutenant Commander, Dental Corps
United States Navy

A thesis submitted to the Faculty of the
Prosthodontics Graduate Program
Naval Postgraduate Dental School
Uniformed Services University of the Health Sciences
In partial fulfillment of the requirements for the degree of
Master of Science
in Oral Biology
June 2021

## ACKNOWLEDGMENTS

I would like to thank my mentors, CAPT Anton Petrich and LCDR Stacy Yu, for their invaluable guidance and involvement in my professional development.

I would also like to thank Dr. Jeffrey Kim and the research department for advising and encouraging me throughout my research.

I am also grateful for LCDR Patrick McCurdy, Dr. Peter Liacouras, Mrs. Nicole McMinn, and HM2 Vernon Barnett for their much needed assistance and tireless contributions to research.

And most importantly, to my family, friends, and colleagues for their never ending support.

# DEDICATION

To my wife, Irene, and daughter, Camila

# DISCLAIMER

The views presented here are those of the author and are not to be construed as official or reflecting the views of the Uniformed Services University of the Health Sciences, the Department of Defense or the U.S. Government.

# ABSTRACT

OCCLUSAL ACCURACY OF MILLED DENTURE TEETH WITH DIFFERENT MORPHOLOGIES

TUAN TRAN, DMD, 2021

Thesis directed by: Jeffrey J. Kim, DDS, PhD

Associate Professor, Research Department, NPDS, NMLPDC

**Introduction:** Currently, it is not known if occlusal morphology affects the accuracy of computer-aided design & computer-aided manufacturing (CAD/CAM) milled denture teeth. **Objective**: This study compared the occlusal accuracy of milled denture teeth designed from three molds: non-anatomical (0°), semi-anatomical (20°), and anatomical teeth (40°). **Methods**: Ten identical posterior sextants from each of the three molds were milled (imes-icore CORiTEC 350i Loader), scanned (Freedom HD), and digitally evaluated for accuracy (Materialise 3 Matic). **Results**: Analysis revealed minimal occlusal differences between stock and milled denture teeth. The largest discrepancies were within grooves, pits, and embrasures. Accuracy was calculated by using a computer generated point based comparison analysis feature. No significant difference (p-value = 0.44) in milling accuracy was observed among three molds (0°, 20°, and 40°). **Conclusion**: Within the limitations of this study, copy milling provides a smooth surfaced, occlusal reproduction of non-anatomical, semi-anatomical, and anatomical stock denture teeth with similar accuracy.

# TABLE OF CONTENTS

# LIST OF TABLES

# LIST OF FIGURES

# LIST OF ABBREVIATONS

| | |
|---|---|
| CAD | Computer-aided design |
| CAM | Computer-aided manufacturing |
| PMMA | Polymethylmethacrylate |
| STL | Standard tessellation language |

# CHAPTER 1: Introduction

Computer-aided design and computer-aided manufacturing (CAD-CAM) dental restorations have become more common with complex fixed and removable dental prostheses. With recent development of digital technology, dentures fabricated with CAD-CAM are regarded as clinically acceptable, accurate, fast, and reproducible[2, 4, 6, 7, 10]. Previous study showed the intaglio surface of denture bases made by digital technology are reliable and acceptable[4]. In 2018, Goodacre *et al*. investigated tooth movement resulting from the fabrication of dentures using various methods[3]. The study found that there was a “negative” occlusal discrepancy with milled monolithic dentures which resulted in prosthetic teeth being shorter than designed (overmilled restorations)[3]. In general, the effects of occlusal discrepancies can be magnified by a factor of four in patients with opposing dentures and second molar occlusion[8]. This error could negatively affect the patient's vertical dimension of occlusion, function, comfort, and esthetics and requires time-consuming chairside adjustments[1]. It has been suggested that natural teeth can perceive a difference of 20-35 microns between teeth, implant patients can distinguish approximately 50 microns, and complete denture patients can perceive on average 100 microns[9].

One potential explanation for the "tooth movement" in CAD-CAM fabrication is the complexity in milling tooth morphology[1, 11]. Digitally designed teeth and stock manufactured denture teeth are available in many different forms, sizes, shapes, lengths, and cusp angles to address the patients’ needs. They are selected based on several factors, including the patients’ esthetics, anatomy, neuromuscular coordination, and functional habits. Several occlusal concepts exist and posterior teeth can be arranged using anatomical teeth with high cusp angles or non-anatomical teeth with a flat plane design, based on the patient's needs and functional ability. When the teeth are digitized, surfaces of the teeth are plotted using several points to create geometric approximations in a standard tessellation language (STL) format file. As STL files are digitally prepared for manufacturing, a strategy for machining, called the "tool path", is calculated. This tool path is limited to the milling machine's tools (e.g., milling burs size, material composition, and design) and capabilities (e.g., dynamic motions of rotation and multi-axis movement). One important limitation is referred to as mill- or drill- compensation, which occurs when the drill tool is wider than the details it is trying to create. The mill-compensation results in less surface details and, ultimately, less accuracy[5]. Manufacturers currently recommend that restoration preparations (e.g., crowns), should be smooth and rounded to reduce the amount of overmilling in the intaglio surface.

The milling machine accuracy of rounded vs. sharp angled dental restorations has been studied by comparing the internal fit of CAD-CAM restorations with their prepared sites[5]. However, the accuracy of the occlusal surface has not been reported. The negative occlusal discrepancy previously noted with digital dentures may be due to the overmilling of the dental anatomy. Therefore, the main objective of this study is to compare the occlusal accuracy of milled denture teeth designed from three molds: non-anatomical (0°), semi-anatomical (20°), and anatomical teeth (40°). The null hypothesis is there is no difference in occlusal accuracy among milled denture teeth from three molds. As CAD-CAM restorations are becoming readily available chairside with more complex treatment, in both fixed and removable prostheses, the occlusal accuracy is of increasing importance. Understanding the limitations of technology will allow better customization of denture teeth while maintaining accuracy in designs and dimensions.

# CHAPTER 2: Materials and methods

## DIGITAL SCANNING

A total of 30 posterior sextants were copy-milled, scanned, and evaluated using non-anatomical (0°), semi-anatomical (20°), and anatomical denture teeth (40°) (Portrait IPN). Four posterior denture teeth of each mold were set up for flat plane occlusion in a wax holder (**Figure 1**). Each of three different sextants was prepared with a scanning preparation spray (Sirona CEREC Optispray) and digitally scanned using a laboratory based white light scanner (DOF Freedom HD), which had an accuracy and precision of 7µm (DOF Freedom HD). Each file was subsequently converted into a reference standard tessellation language (STL) digital file ("true value" control).

### SAMPLE MILLINGS

Next, STL models were copy-milled into 10 polymethylmethacrylate (PMMA, Ivoclar Vivadent Ivotion) replicates using a five-axis milling machine (imes-icore CORiTEC 350i Loader) (**Figure 2**). Ten copies were milled from each of the three reference STL files, totaling in 30 milled samples. All milled samples were steam cleaned, sprayed with scanning preparation spray (Sirona CEREC Optispray), scanned with the laboratory scanner (DOF Freedom HD), and converted into STL files.

## Surface Matching

STL files were superimposed using surface-matching software (Materialise 3matic). A global registration function was used to find 10,000 points in common between the true value control and the milled files. Data sets were trimmed to streamline data analysis. Only the areas of interest, namely the occlusal surfaces, were analyzed by cropping data sets within a group using the same borders (**Figure 3**). Color surface maps were also created using a 3D comparison function (Materialise 3matic) to visually display the direction and amount of denture tooth discrepancy (**Figure 4**). Color spectra were set to have a maximum critical value of +/- 0.25mm.

Accuracy was calculated by using a computer generated point based comparison analysis feature. Unsigned and signed mean global error values and standard deviations based on the accuracy were recorded. One-way ANOVA was used to compare the signed mean global errors from three molds.

# CHAPTER 3: Results

Unsigned mean global error calculates total amount of error, without respect to the negative or positive nature of the error. Signed data, on the other hand, consider a positive or negative direction associated with the error like a vector. The results for unsigned data show 0 degree group had the largest mean global error (± standard deviation) of 0.0613 ± 0.0549 mm; 20 degrees was 0.0401 ± 0.0377 mm; and 40 degree had the smallest, with 0.034 ± 0.0358 mm (**Table 1** and **Figure 6**). Signed mean global errors were 0.0244mm for 0 degrees, -0.008 for 20 degrees, and -0.0110 for 40 degrees (**Table 1** and **Figure 6**).

For the following statistical analyses, only signed data were used. To determine whether the milling machine produced denture teeth accurately, we used one sample t-test to compare signed mean global errors from ten replicates. For 0, 20 and 40 degree groups, one sample t-test results were $p = 0.29$, $p = 0.6$, and $p = 0.44$ respectively.

Next, one-way analysis of variance (ANOVA) was used to determine whether there were any statistically significant differences among the means of signed mean global errors from three mold groups (0° vs. 20° vs. 40°). We found no significant difference (p-value = 0.44 and f-statistic value = 0.84) in milling accuracy among three mold groups.

**Figures 4** and **5** visualize the errors among the reference and milled samples. The largest discrepancies were mainly within grooves, pits, and embrasures, as seen in the color map and cross sectional views. The figures only show one sample from each group, not a composite of all samples, but are representative of the general error patterns observed.

# CHAPTER 4: Discussion

Our results implicate the following (1) the milling machine we used is capable of accurately replicating denture teeth (one sample t test, $p>0.05$), and (2) different occlusal morphologies did not influence the accuracy of milling processes (one-way ANOVA $p = 0.44$).

Of note, the largest unsigned mean error was in the 0 degree group, at 61 microns. This is interesting because it is counter-intuitive from what is generally believed. Currently, it is assumed that it is easier for milling machines and cutting burrs to navigate 0 degrees plane (a flat surface) than 40 degrees plane (sharp angles and corners). A closer look at denture teeth occlusal morphologies revealed that non-anatomical teeth have sharper angles to their design, especially the grooves in relation to the occlusal surface, even though they are designated as “0 degrees”. Areas of these largest discrepancies were mainly away from the primary occlusal contacting areas, which are usually the cusp tips or inclines. Additionally, with the 40 degrees, the grooves are more rounded and blend in better with the rest of the tooth anatomy. However, these dissimilarities in the mean global errors among three mold groups did not lead to statistically significant difference.

Our results support the Goodacre study where negative occlusal discrepancies were observed with digitally fabricated dentures[3]. There was a difference between these studies, however, in the magnitude of discrepancies. The previous study showed a signed error of -60 microns, but in the posterior teeth, the error was approximately -120 microns. This study, on the other hand, had an average mean signed error of -15 microns of all three molds. The difference in the magnitude can be explain, in part, by differences in denture teeth fabrication protocols, milling machine precision, starting material used for milling, and cutting burr size and design.

Limitations to this study include using only one milling machine and one type of restorative material. The results are based on the accuracy of these machines and the materials used in the study, however there are other machines, materials, and lab protocols, which could yield different results. Secondly, this study only evaluated the accuracy of four posterior teeth. The Goodacre study milled a whole denture, but found that the most amount of discrepancy was in the posterior teeth[3]. It is possible that milling a whole denture or arch of teeth could lead to slightly different results. Thirdly, we intentionally decided to focus on signed mean global errors for statistical analyses because we found that removing the directionality inflated the errors which most likely will lead to biases and may not be clinically relevant.

Our study suggests digital workflow is an accurate alternative for prefabricated, stock denture teeth, and denture teeth can be milled using CAD-CAM with high levels of accuracy. While 0 degree, non-anatomical teeth had the largest amount of error, it is still well within the clinically acceptable range. Results from this study can be used in applications for fixed and removable restorations, and from single tooth to full mouth cases. The main strength of this study is that we were able to independently verify accuracy and precision of milling machines, digital scanning, and denture teeth fabrication protocol. Future research could look to see how occlusal milling accuracy is affected with other restorative materials, and find out the clinical relevant, *in-vivo* threshold or tolerance of milling discrepancies.

# CHAPTER 5: Conclusions

Within the limitations of this study, copy-milled denture teeth accurately replicate the smooth surface occlusal morphology of manufactured denture teeth. The results of this study suggest that milled restorations would preserve occlusion. While the largest discrepancies were observed in pits and grooves, these areas would have minimal clinically relevant effects on occlusion.

Table 1. Mean Global Error

| Mean Global Error | | | | | |
|---|---|---|---|---|---|
| | | Unsigned | | Signed | |
| **Groups** | **N** | **Mean (mm)** | **Std. Dev.** | **Mean (mm)** | **Std. Dev.** |
| 0° (Non-anatomical) | 10 | 0.0613 | 0.0549 | -0.0244 | 0.07 |
| 20° (Semi-anatomical) | 10 | 0.0401 | 0.0377 | -0.008 | 0.05 |
| 40° (Anatomical) | 10 | 0.034 | 0.0358 | -0.011 | 0.048 |

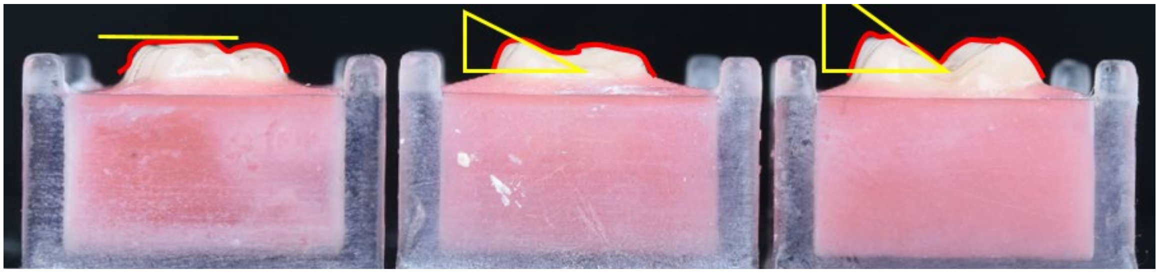


**Figure 1.** **Anatomic molds.** Posterior denture teeth of different anatomical molds were set up for flat plane occlusion in a wax holder: 0° non-anatomical, 20° semi-anatomical, and 40° anatomical, respectively.

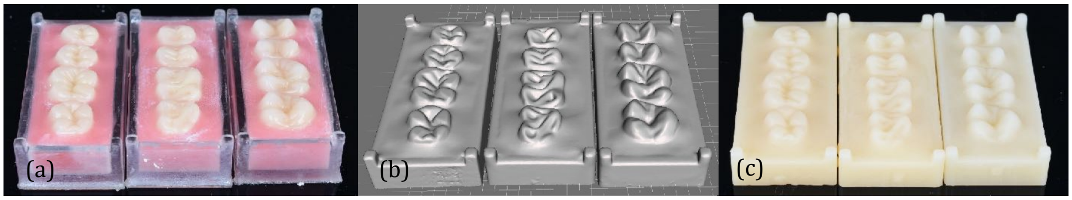
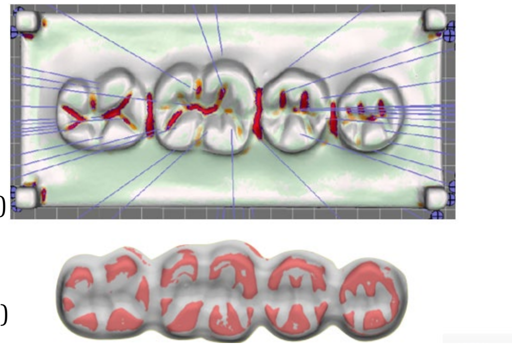



**Figure 2.** **Teeth sample molds.** (a) Denture teeth were prepared and digitally scanned using a laboratiry scanner. (b) Each file was then converted into a reference digital STL models. (c) STLs were copy-milled into PMMA replica samples



(a)

(b)

**Figure 3.** **Digitized data sets.** (a) STL sample models were superimposed with the reference file using surface-matching software. This was done using a global registration function. (b) Data sets were cropped and trimmed to limit data analysis to only the areas of interest, namely the occlusal surfaces.

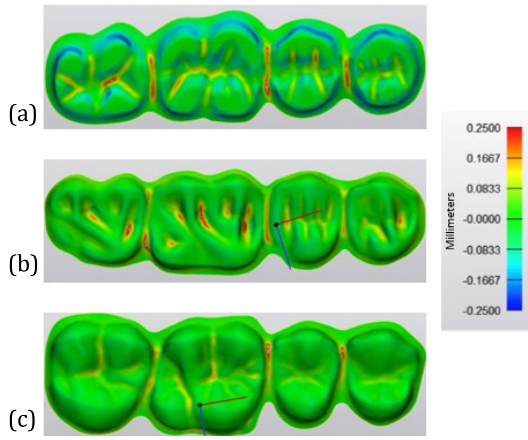
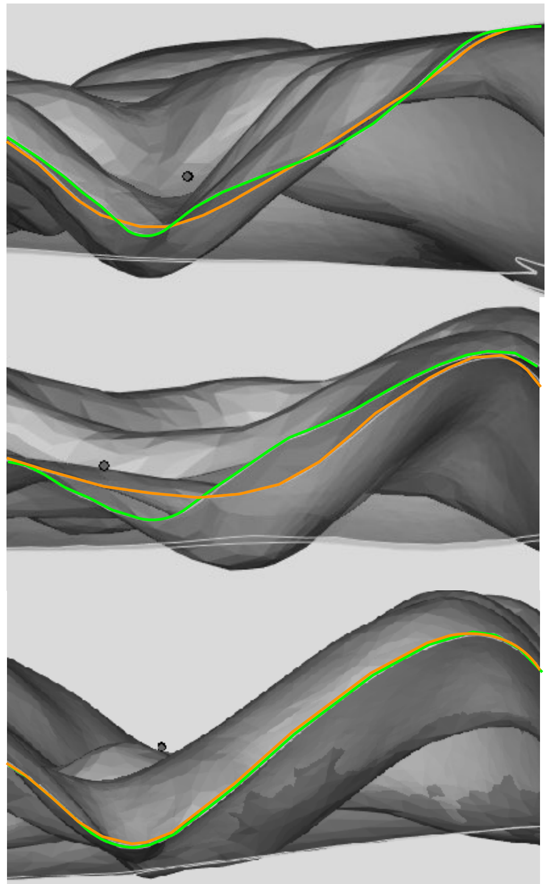



**Figure 4.** **Color surface maps.** Color surface maps were created using a 3D comparison function to visually diplay the direction and amout of denture tooth discrepancy. Color spectra were set to have a maximum critical value of +/- 0.25mm. (a) 0° non-anatomical, (b) 20° semi-anatomical, and (c) 40° anatomical



(a)

(b)

(c)

**Figure 5.** **Cross section of discrepancies.** In a cross sectional view, discrepancies can be visualized with positive and negative errors. The two different lines represent the control (green) and the milled sample (orange). These images are only showing one sample from each group, not a composite of all samples. (a) 0° non-anatomical, (b) 20° semi-anatomical, and (c) 40° anatomical

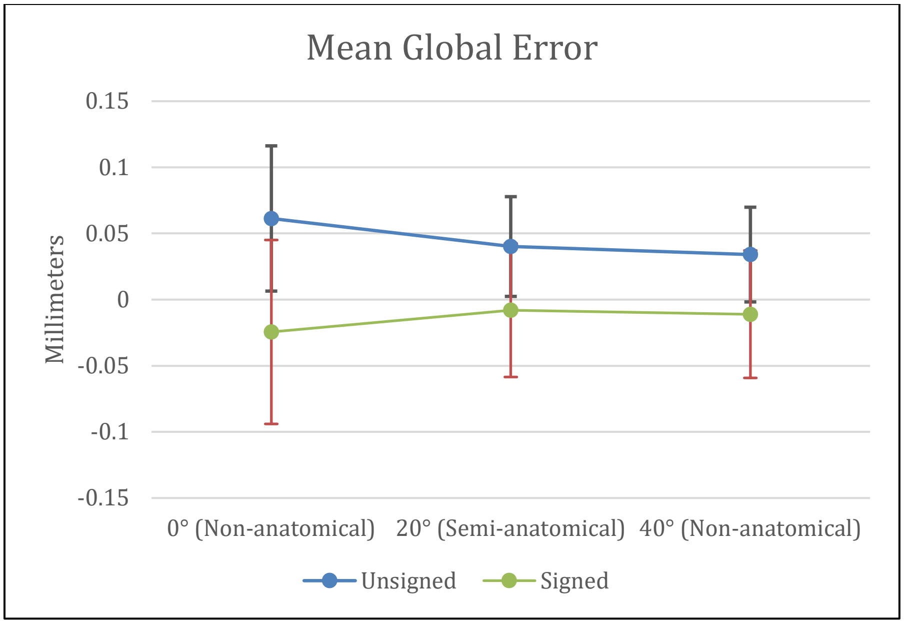



**Figure 6.** **Mean global error graph.** The results show the 0 degree group had the largest unsigned mean global error of 0.0613mm and a standard deviation of 0.0549; 20 degrees was 0.0401mm and standard deviation 0.0377; and the 40 degree had the smallest, with 0.034mm and standard deviation 0.0358. The signed mean global error was -0.0244mm for 0 degrees, -0.008 for 20 degrees, and -0.0110 for 40 degrees

# REFERENCES


1. Abduo J, Lyons K, Bennamoun M. Trends in computer-aided manufacturing in prosthodontics: a review of the available streams. Int J Dent. 2014;2014:783948. doi:10.1155/2014/783948

2. Bidra AS, Taylor TD, Agar JR. Computer-aided technology for fabricating complete dentures: systematic review of historical background, current status, and future perspectives. J Prosthet Dent. 2013;109(6):361-366. doi:10.1016/S0022-3913(13)60318-2

3. Goodacre BJ, Goodacre CJ, Baba NZ, Kattadiyil MT. Comparison of denture tooth movement between CAD-CAM and conventional fabrication techniques. J Prosthet Dent. 2018;119(1):108-115. doi:10.1016/j.prosdent.2017.02.009

4. Goodacre BJ, Goodacre CJ, Baba NZ, Kattadiyil MT. Comparison of denture base adaptation between CAD-CAM and conventional fabrication techniques. J Prosthet Dent. 2016;116(2):249-256. doi:10.1016/j.prosdent.2016.02.017

5. Goujat A, Abouelleil H, Colon P, et al. Marginal and internal fit of CAD-CAM inlay/onlay restorations: A systematic review of in vitro studies. J Prosthet Dent. 2019;121(4):590-597.e3. doi:10.1016/j.prosdent.2018.06.006

6. Kanazawa M, Inokoshi M, Minakuchi S, Ohbayashi N. Trial of a CAD/CAM system for fabricating complete dentures. Dent Mater J. 2011;30(1):93-96. doi:10.4012/dmj.2010-112

7. Kattadiyil MT, AlHelal A. An update on computer-engineered complete dentures: A systematic review on clinical outcomes. J Prosthet Dent. 2017;117(4):478-485. doi:10.1016/j.prosdent.2016.08.017

8. Mahler DB. Inarticulation of complete dentures processed by the compression molding technique. J Prosthet Dent. 1951;1(5):551-559. doi:10.1016/0022-3913(51)90040-6

9. Misch CE. Contemporary implant dentistry. 3rd ed. Mosby; 2008.

10. Schwindling FS, Stober T. A comparison of two digital techniques for the fabrication of complete removable dental prostheses: A pilot clinical study. J Prosthet Dent. 2016;116(5):756-763. doi:10.1016/j.prosdent.2016.03.022

11. Tapie L, Lebon N, Mawussi B, Fron-Chabouis H, Duret F, Attal JP. Understanding dental CAD/CAM for restorations--accuracy from a mechanical engineering viewpoint. Int J Comput Dent. 2015;18(4):343-367.