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Development of Novel Polymeric Articulating Papers for Enhanced Occlusal Contact Assessment in Dentistry

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Abstract

Traditional articulating papers, a mainstay in occlusal analysis, often exhibit limitations in consistency and difficulty with quantitative data analysis. This study explores the development of novel articulating papers utilizing advanced polymeric materials. These novel papers aim to address the shortcomings of traditional options by potentially improving: (1) sensitivity and resolution for capturing occlusal contacts, (2) consistency and reproducibility of contact readings, and (3) durability and reusability. The successful development of such polymeric articulating papers could offer significant advantages for dentists by providing a more reliable and quantitative tool for occlusal analysis, ultimately contributing to improved diagnosis and treatment planning of occlusal disorders. This study is further aimed to evaluate and compare the reproducibility of five different articulating papers and the T-Scan Occlusal Analysis System in assessing occlusal contacts. Occlusal analysis plays a crucial role in diagnosing and managing occlusal disorders in dentistry, and reliable assessment tools are essential for accurate treatment planning. Five commonly used articulating papers with varying thicknesses and sensitivities were selected, along with the T-Scan system, which offers digital occlusal analysis. A series of occlusal contacts were recorded using each method on a standardized dental model. The reproducibility of occlusal contact recordings was assessed by repeating measurements multiple times. Results indicated significant differences in reproducibility among the different articulating papers and the T-Scan system. Understanding the reproducibility of occlusal analysis tools is vital for clinicians to make informed decisions regarding their selection and use in clinical practice.

Keywords: Polymeric materials, occlusal analysis, articulating paper, T-Scan system, occlusal contacts, dental model, occlusal disorders

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INTRODUCTION

Dentistry, a field of healthcare medicine, is significantly influenced by its materials and equipment. Occlusion, a topic commonly discussed in various dental fields, originates from the Latin verb "occludere," meaning 'to close up.' [1]. Failure to control the occlusion can cause different complications including dental pain/ discomfort, mobility of teeth, pathologic wear of teeth, fracture of tooth material or fracture of restoration, negative postural changes, and TMJ dysfunction issues [2]. Therefore, a comprehensive understanding of occlusion must be grounded in knowledge of the physiological masticatory system, including insights into functional geometry and the transformation of dysfunction that can lead to pathology [3].

An occlusal contact can be analyzed based on its shape, size, and position, irrespective of whether it makes occlusal or close-occlusal contact with the antagonist's teeth. Occlusal contacts denote the points of contact between the opposing dentition when the inter-occluding distance between the occluding surfaces is less than 50 µm, while close occlusal contacts occur within a range of 50 µm to 350 µm [4,5]. For the proper functioning of the masticatory system, these occlusal contacts need to be synchronized with the stomatognathic apparatus and hence assessment of the given occlusion is of paramount importance for remedying the various occlusal issues mentioned before.

In terms of recording and evaluating the occlusal contacts, it can be achieved in two ways, qualitative evaluation and quantitative evaluation. The qualitative methods of localization of the occlusal contacts amongst the occluding surfaces can be viewed and analyzed; sequencing and density of the contacts cannot be recorded. It is often assumed that the density of occlusal contacts corresponds to the darkness of the reproduced marks, but this is not a reliable criterion for evaluation. Carbon papers, commonly used for this purpose, vary in width, dye type, material, and thickness, resulting in either point or surface transfer type marks [6]. The primary limitations of using carbon paper include susceptibility to distortion and damage upon contact with oral fluids (such as saliva), as well as their inflexible base material. These factors can lead to the formation of pseudo contact markings or false positive markings. Some research recommends the utilization of silk strips for more accurate readings [7]. Soft indicator materials, due to their texture quality, typically do not produce pseudo markings. However, silk strips may lose their marking potential when the stain components dry out or are lost, and contact with saliva can distort the material. Carbon foils are thinner than silk and paper and can give more accurate readings than the above mentioned. But under decreased pressure and on glossy surfaces, their marking capacities are seen to be less evident. This means that to achieve accurate readings from the foils in clinical use a great amount of pressure needs to be rendered [8]. Because of these discrepancies, occlusal indicators are primarily used qualitatively and require interpretation by the attending dentist. Subsequently, feedback is obtained from the patient regarding whether the restoration still feels "high." (6). The quantification and timing of occlusal contacts are the best studies using quantitative methods. The systems that have been used and employed in clinical practices are electro-optic and resistive systems [9].

The T-Scan mechanism is a dental tool designed to assess the relative distribution of occlusal force within the mouth, utilizing a pressure-mapping sensor for intraoral recording. Its components comprise a sensor with support, a handle assembly, the main system unit, dedicated computer software, and a printer. The sensor typically has a thickness of 0.1mm [10].

This research aimed to assess and compare the consistency of Carbon papers when used alongside the T-Scan Occlusal Evaluation System across different patient categories, including dentate individuals with a complete set of teeth, complete denture patients, and fixed partial denture patients. The objective was to determine the effectiveness of five different Carbon papers in replicating occlusal contact patterns compared to the T Scan system. Through meticulous evaluation and comparison, the study sought to provide valuable insights into the reliability and accuracy of Carbon papers in different clinical scenarios.

Review of Literature

Makofsky, H. W. (2000) [11]. Investigated the impact of forward head posture (FHP) on the initial occlusal contact pattern (IOCP) to shed light on this significant area of study. Thirty-nine healthy participants, aged 10 to 74 years, underwent a series of assessments where the IOCP was documented in four distinct head positions utilizing the T-Scan Occlusal Diagnostic System. This study prompted inquiries into the link between FHP and occlusion. Millstein, P., & Maya, A. (2001) [12]. Conducted a study aimed at assessing the precision of occlusal contact marking indicators and the consistency of their performance by quantifying the areas of contact markings on occlusal surfaces. They utilized occlusal indicators constructed from paper, film, and silk, evaluating ten different indicators by applying them to articulator-mounted, impact-resistant casts. Their findings revealed that the thickness, color, and composition of the indicators independently and collectively influenced the size of the markings. They concluded that variations exist among all indicators, and their markings may lack repeatability, even when used under similar conditions. DeLong, R., Ko, C.-C. (2002) [13]. emphasized the necessity for a tool capable of identifying and quantifying occlusal parameters without interference caused by the evaluation technique, as precise quantitative measures of occlusal contacts are crucial in studying chewing dysfunction. Their findings indicated that the favored approach for computing contacts entails utilizing virtual casts aligned with virtual interocclusal records, and reliable occlusal contacts can be derived from aligned virtual casts. Davies, S., Al-Ani, Z., Jeremiah, H., Winston, D. & Smith, P. (2005) [14]. identified an issue with inaccuracies in transferring information between clinicians and technicians concerning occlusal contacts during the fabrication of indirect restorations. To address this, their research aimed to assess the reliability of a fast and straightforward method for recording occlusal contacts. Carbon papers (specifically 40-mm Carbon paper; Bausch Carbon Papers, Nashua, NH) were utilized to record and assess static and dynamic occlusal contacts in 29 subjects without any missing functional units. Carey, J. P et. al. (2007) [15]. conducted a study to explore whether there exists a direct correlation among the carbo impression area and the applied occlusal force. Findings from their investigation indicated that although there was no direct correlation between the impression area and the applied force, there was an observed trend of increasing marked areas with higher applied loads.

Materials and Methods

This is in-vivo study aimed to assess and compare the reproducible properties of five commercially available Carbon papers and the T Scan Occlusal Evaluation System. The research was carried out at the Department of Prosthodontics and Crown & Bridge, School of Dental Sciences, Krishna Institute of Medical Sciences Deemed to be University, Karad, Maharashtra.

The size of study for participant's determination was done using the mathematical formula.

$$n = \frac{4\ SD^2}{(M \times \mathcal{E})^2}$$

n = sample size

SD = Standard Deviation

M = Mean

With the above formula, the sample size derived was 30 patients. Three categories of patients were chosen for the study; wherein CATEGORY A, B, and C were the experimental category and category CG being the control category (Table 1). The categorying of the patients was done into three different experimental categories considering inclusion and exclusion criteria. The criteria for admittance and elimination are mentioned in (Table 2).

Table 1. Division of Study Participants and the Control Category.

Category	**Categories Of Patients**
CATEGORY A (n = 10)	Patients using complete denture (one-month post denture delivery)
CATEGORY B (n = 10)	Patients with one or more fixed partial denture in posterior teeth (unilateral/bilateral) (one-month post-insertion)
CATEGORY C (n = 10)	Dentulous individuals with full complement teeth
CONTROL CATEGORY (CG)(n = 30)	T – Scan Occlusal Evaluation of all the above patients

Table. 2. Criteria for Admittance and Elimination.

Admittance criteria	Elimination criteria
Complete Denture Patients	
Patients providing informed consent	Patients with ill-fitting dentures
Patients comfortable with the existing denture	Patients with temporomandibular symptomatology
Healthy intraoral conditions	Presence of any intraoral lesions
Angles Class I occlusion	Patients with any para - functional habits
Complete Dentulous Patients	
Non-decayed maxillary teeth	Direct and indirect restorations
No orthodontic brackets	Malaligned teeth
Healthy intraoral conditions	High-grade dental stains and/or calculus
No deleterious habits	Parafunctional habits
Angles Class I occlusion	History of previous orthodontic treatments
Patients With Fixed Partial Dentures	
Unilateral or bilateral prosthesis present	Absence of any of the posterior teeth
Intact maxillary and mandibular posteriors	Patients with TMD symptomatology
	Patients with any deleterious habits.

Materials Used in The Study With Their Specifications.

a. Bausch Arti-Check Carbon Papers Micro Thin - 40µ thick.
b. Whip mix Ardent Carbon paper - 63 µ thick.
c. Coltene Whaledent Hanel Carbon paper- 80µ thick.
d. Neelkanth Carbon Paper – 180 µ thick.
e. Bausch Progress100 Carbon paper – 100 µ thick.
f. T Scan Occlusal Evaluation System – 60 µ thick.

Equipment Used in The Study with Their Specifications.

a. Bausch Carbon Paper Forceps "Miller" - BK 142
b. Intraoral occlusal photography mirrors – Stainless Steel
c. Photographic setup – DSLR Camera, Ring Flash, Shutter
d. Set of diagnostic instruments- mouth mirror, straight probe, tweezers

Methodology

Participants were in allocated one of the three categories: CATEGORY A (n = 10)- Patients using complete denture. (one-month post denture delivery), CATEGORY B (n = 10) Patients with one or more fixed partial denture in posterior teeth (unilateral / bilateral; one-month post-insertion) and CATEGORY C (n = 10) Dentulous individuals with full complement teeth. Before shortlisting them for the execution of the study, all the patients were informed about the upcoming study in their language, and informed consent was obtained before starting the study. The age category of CATEGORY A was 55 -70 years, and CATEGORY B and CATEGORY C patients were 20 years – 40 years respectively; males and/or females. A detailed case history was taken for each of these study category participants which revealed details about their intraoral dental condition.

OBSERVATION AND RESULTS

Results

In Complete Denture (CD) category, Bausch Progress100 Carbon paper100 µ showed 80% match with T Scan occlusal evaluation system readings; Coltene Whaledent Hanel Carbon paper 80µ showed 80% match with T Scan occlusal evaluation system readings; showed only 30% match with T Scan occlusal evaluation system readings; Bausch Arti-Check Carbon Papers Micro Thin - 40µ showed 80% match with T Scan occlusal evaluation system readings and Whip mix Ardent Carbon paper - 63 µ showed 80% match with T scan. There was a meaningful distinction in match within CD category among different types of Carbon papers. In Fixed Dental Prostheses (FDP) category, Bausch Progress100 Carbon paper100 µ showed 30% match with T Scan occlusal evaluation system readings; Coltene Whaledent Hanel Carbon paper 80µ showed 20% match with T Scan occlusal evaluation system readings; Bausch Arti-Check Carbon Papers Micro Thin - 40µ showed 90% match with T Scan occlusal evaluation system readings; Whip mix Ardent Carbon paper - 63 µ showed 80% match with T Scan occlusal evaluation system readings while none of the Carbon paper samples in Neelkanth Carbon Paper – 180 µ showed match with T Scan occlusal evaluation system readings. There was a meaningful distinction in match within FDP category among different types of Carbon papers. In patients with full complement teeth or Natural Dentition (ND) category, Bausch Progress100 Carbon paper100 µ showed 20% match with T Scan occlusal evaluation system readings; Coltene Whaledent Hanel Carbon paper 80µ showed 70% match with T Scan occlusal evaluation system readings; Neelkanth Carbon Paper – 180 µ showed only 30% match with T Scan occlusal evaluation system readings; Bausch Arti-Check Carbon Papers Micro Thin - 40µ showed 70% match with T Scan occlusal evaluation system readings and Whip mix Ardent Carbon paper - 63 µ showed 70% match with T Scan occlusal evaluation system readings. There was a meaningful distinction in match within ND category among different types of Carbon papers. (Table 3)

Table 3. Comparison of match/no match within each category among different types of Carbon papers.

Category		Bausch progress100 carbon paper 100 µ	Coltene whaledent hanel carbon paper 80µ	Neelkanth carbon paper 180 µ	Bausch arti-check carbon papers micro thin - 40µ	Whip mix ardent carbon paper - 63 µ	p-value
CD	Match	8 (80)	8 (80)	3 (30)	8 (80)	8 (80)	0.049*
	No match	2 (20)	2 (20)	7 (70)	2 (20)	2 (20)	
FDP	Match	3 (30)	2 (20)	0 (0)	9 (90)	8 (80)	0.001*
	No match	7 (70)	8 (80)	10 (100)	1 (10)	2 (20)	
ND	Match	2 (20)	7 (70)	3 (30)	7 (70)	7 (70)	0.042*
	No match	8 (80)	3 (30)	7 (70)	3 (30)	3 (30)	

*Chi-square test; * indicates meaningful distinction at $p \leq 0.05$*

Table 4. Comparison of match/no match within each paper among different dentition categories.

Paper	Category	Match	No match	χ^2 value	p-value
Bausch Progress100 Carbon paper 100 µ	CD	8 (80)	2 (20)	8.416	0.015*
	FDP	3 (30)	7 (70)		
	ND	2 (20)	8 (80)		
Coltene Whaledent Hanel Carbon paper 80µ	CD	8 (80)	2 (20)	8.416	0.015*
	FDP	2 (20)	8 (80)		
	ND	7 (70)	3 (30)		
Neelkanth Carbon Paper – 180 µ	CD	3 (30)	7 (70)	3.750	0.153 (NS)
	FDP	0 (0)	10 (100)		
	ND	3 (30)	7 (70)		
Bausch Arti-Check Carbon Papers Micro Thin - 40µ	CD	8 (80)	2 (20)	1.250	0.535 (NS)
	FDP	9 (90)	1 (10)		
	ND	7 (70)	3 (30)		
Whipmix Ardent Carbon paper - 63 µ	CD	8 (80)	2 (20)	0.373	0.830 (NS)
	FDP	8 (80)	2 (20)		
	ND	7 (70)	3 (30)		

*Chi-square test; * indicates meaningful distinction at $p \leq 0.05$; NS: Non-significant.*

For Bausch Progress100 Carbon paper100 µ, 80% of samples showed match in CD category; 30% of samples showed match in FDP category and 20% samples showed match in ND category. There was a meaningful distinction in match within Bausch Progress100 Carbon paper100 µ category among different types of dentitions. For Coltene Whaledent Hanel Carbon paper 80µ showed, 80% sample showed match in CD category; 20% samples showed match in FDP category and 70% samples showed match in ND category. There was a meaningful distinction in match within Coltene Whaledent Hanel Carbon paper 80µ category among different types of dentitions. For Neelkanth Carbon Paper 180 µ, 30% sample showed match in CD category; no samples showed match in FDP category and 30% samples showed match in ND category. There was a non-meaningful distinction in match within Neelkanth Carbon Paper 180 µ, category among different types of dentitions. For Bausch Arti-Check Carbon Papers Micro Thin - 40µ, 80% sample showed match in CD category; 90% samples showed match in FDP category and 70% samples showed match in ND category. There was a non-meaningful distinction in match within Bausch Arti-Check Carbon Papers Micro Thin - 40µ category among different types of dentitions. For Whip mix Ardent Carbon paper - 63 µ, 80% sample showed match in CD category; 0% samples showed match in FDP category and 270% samples showed match in ND category. There was a meaningful distinction in match within Whip mix Ardent Carbon paper - 63 µ category among different types of dentitions (Table 4)

Table 5. Pair-wise comparison between CD and FDP category.

Paper	Category	Match	No match	χ^2 value	p-value
Bausch Progress100 Carbon paper100 µ	CD	8 (80)	2 (20)	5.051	0.025*
	FDP	3 (30)	7 (70)		
Coltene Whaledent Hanel Carbon paper 80µ	CD	8 (80)	2 (20)	7.200	0.007*
	FDP	2 (20)	8 (80)		
Neelkanth Carbon Paper 180 µ	CD	3 (30)	7 (70)	3.259	0.060 (NS)
	FDP	0 (0)	10 (100)		
Bausch Arti-Check Carbon Papers Micro Thin - 40µ	CD	8 (80)	2 (20)	0.392	0.531 (NS)
	FDP	9 (90)	1 (10)		
Whip mix Ardent Carbon paper - 63 µ	CD	8 (80)	2 (20)	0.000	1.000 (NS)
	FDP	8 (80)	2 (20)		

*Fisher exact test; * indicates meaningful distinction at p≤0.05; NS: Non-significant.*

Table 5 shows that there was a meaningful distinction between CD and FDP categories for the match in Bausch Progress100 Carbon paper100 µ. There was a meaningful distinction between CD and FDP categories for the match in Coltene Whaledent Hanel Carbon paper 80µ papers. There was a non-meaningful distinction between CD and FDP categories for the match in Neelkanth Carbon Paper 180 µ papers. There was a non-meaningful distinction between CD and FDP categories for the match in Bausch Arti-Check Carbon Papers Micro Thin - 40µ. There was a non-meaningful distinction between CD and FDP categories for match in Whip mix Ardent Carbon paper - 63 µ papers.

Table 6. Pair-wise comparison between CD and ND category.

Paper	Category	Match	No match	χ^2 value	p value
Bausch Progress100 Carbon paper 100 µ	CD	8 (80)	2 (20)	7.200	0.007*
	ND	2 (20)	8 (80)		
Coltene Whaledent Hanel Carbon paper 80µ	CD	8 (80)	2 (20)	0.267	0.606 (NS)
	ND	7 (70)	3 (30)		
Neelkanth Carbon Paper – 180 µ	CD	3 (30)	7 (70)	0.000	1.000 (NS)
	ND	3 (30)	7 (70)		
Bausch Arti-Check Carbon Papers Micro Thin - 40µ	CD	8 (80)	2 (20)	0.267	0.606 (NS)
	ND	7 (70)	3 (30)		
Whip mix Ardent Carbon paper - 63 µ	CD	8 (80)	2 (20)	0.267	0.606 (NS)
	ND	7 (70)	3 (30)		

*chi-square test; * indicates meaningful distinction at p≤0.05; NS: Non-significant.*

Table 6 shows that there was a meaningful distinction between the CD and ND categories for the match in Bausch Progress100 Carbon paper100 µ. There was a non-meaningful distinction between CD and ND categories for the match in Coltene Whaledent Hanel Carbon paper 80µ. There was a non-meaningful distinction between CD and ND categories for the match in Neelkanth Carbon Paper 180 µ papers. There was a non-meaningful distinction between CD and ND categories for the match in Bausch Arti-Check Carbon Papers Micro Thin - 40µ. There was a non-meaningful distinction between CD and ND categories for the match in Whip mix Ardent Carbon paper - 63 µ papers.

Table 7 shows that there was a non-meaningful distinction between the FDP and ND categories for the match in Bausch Progress100 Carbon paper100 µ papers. There was a meaningful distinction between FDP and ND categories for the match in Coltene Whaledent Hanel Carbon paper 80µ. There was a non-meaningful distinction between FDP and ND categories for the match in Neelkanth Carbon Paper 180 µ papers. There was a non-meaningful distinction between FDP and ND categories for the match in Bausch Arti-Check Carbon Papers Micro Thin - 40µ. There was a non-meaningful distinction between the FDP and ND categories for the match in Whip mix Ardent Carbon paper - 63 µ papers.

Table 7. Pair-wise comparison between FDP and ND category.

Paper	Category	Match	No match	χ^2 value	p value
Bausch Progress100 Carbon paper 100 µ	FDP	3 (30)	7 (70)	0.267	0.606 (NS)
	ND	2 (20)	8 (80)		
Coltene Whaledent Hanel Carbon paper 80µ	FDP	2 (20)	8 (80)	5.051	0.025*
	ND	7 (70)	3 (30)		
Neelkanth Carbon Paper – 180 µ	FDP	0 (0)	10 (100)	3.259	0.060 (NS)
	ND	3 (30)	7 (70)		
Bausch Arti-Check Carbon Papers Micro Thin - 40µ	FDP	9 (90)	1 (10)	1.250	0.264 (NS)
	ND	7 (70)	3 (30)		
Whip mix Ardent Carbon paper - 63 µ	FDP	8 (80)	2 (20)	0.267	0.606 (NS)
	ND	7 (70)	3 (30)		

*chi-square test; * indicates meaningful distinction at $p \leq 0.05$; NS: Non-significant.*

CONCLUSION

The identification of occlusal contact markings intraorally using Carbon papers relies on subjective interpretations by individual practitioners, potentially leading to a lack of reliability and accuracy. Therefore, occlusal indicators need to reproduce both qualitative and quantitative markings, aiding dentists in selectively grinding areas with higher occlusal loads. In Complete Denture Prosthesis, Bausch Progress100 Carbon papers of 100 µ thickness demonstrate excellent reproducibility and yield comparable results to T-Scan Occlusal Evaluation Systems. For Fixed Dental Prosthesis, Bausch Arti-Check Carbon Papers Micro Thin (40µ) and Whip mix Ardent Carbon paper (63 µ) are recommended due to their similar performance to T-Scan Occlusal Evaluation Systems. Patients with a full complement of teeth or those without any prosthetic treatment for occlusal equilibration may benefit from Coltene Whaledent Hanel Carbon paper (80µ), Bausch Arti-Check Carbon Papers Micro Thin (40µ), and Whip mix Ardent Carbon paper (63 µ). However, Neelkanth Carbon Paper of 180 µ thickness exhibits minimal accuracy and is therefore considered less reliable across all three categories.

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