

-RXUQDO RI (QJLQHHULQJ 6FL

9ROXPH ,VVXH S

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7HFKQLFDO 6FLHQFHV
\$FDGHP\ RI 5RPDQLD \$
ZZZ MHVL DVWU UR

\$ OHFKDQLFDO (QJLQHHULQJ

5HFHLYHQH
5HFHLYHG LQ UH\$UXMW IURP

\$FFH\$WS\$HPEHU

'HYHORS PHQW RI SUHFHV VLRQDO WUDQ
DSSOLF DWLRQV

%267\$1 ,21

7HFKQLFDO 8QLYHUVLW\ RI 0ROGRYD %G ùWHIDQ FH
5HSXEOLF RI 0ROGRYD

\$EVWUTXHS DSHU FRQWDLQV UHVXOWV RI WKH UHVHD
WUDQVPLVVLRQV RQ VWUXFWXUDO V\$QDG HJLDU VN LQ
ZLWK WKH\$JHDULQJ V \$ \$ 5 \$ & % 7KHUH LV SUHVHQWHG W
WKH WHFKQLFDO VROXWLRQV UHJDUGL\$JHDULQJ HVHDV
DQG RI WKH PHFKDQLFDO HIILFLHQF\ RI WKH WUDQVPLV
WHHWK FRQWDFW ZLWK FRQYH\ FRQFDYH SURILOHV ZL
FXUYDWXUH DQG ZLWK UHGXFHG IULFWLRQV \$JHDULQJ
VSDWLDO WXPEOLQJ UROOLQJ SURFHV VHV RI JHQHUDWL
DUH GHVFULEHG WKH ILHOGV RI DSSOLF DWLRQ RI V
WUDQVPLVVLRQV DUH GHVFULEHG
.H\ZRUGV SUHFHV VLRQDO WUDQVPLVVLRQV EHDULQJ FDS
FRQFDYH FRQFDYH FRQWDFW FRQYH\ FRQFDYH SURILO
UROOLQJ

,QWURGXFWRQ

6WDWHPHQW RI WKH
+RZ WR FRPELQH LQ D VLQJOH PHFI
WKH NLQHPDWLF SRVVLELOLWL
KLJK ORDG EHDULQJ FDSDF
ORVVHV DV VPDOO DV

7KH GHYHORS PHQW RI SUHFHV VLRQDO WUDQVPLVV
HVVHQWLDUO\ SXUVXHG WKH SXUSR VH RIRZGHWRL

&RUUHVSRRGHQFH DGGUHVV LRQ ERVWDQ#FQWV XWP P

%RVWDQ , 'HYHORSPHQW RI SUHFHVVLQRQDO WUDQVFR

FRPELQH LQ D VLQJOH PHFKDQLFDO WUDQVPLVVLRQ
SRVVLEOH KLJK ORDG EHDULQJ FDSDFLW\ DQG HGHU
7KH DFFRPSOLVKPHQW RI WKHVK WKUHH SHUIR
WUDQVPLVVLRQ ZDV WULHG E\ SURSRVLQJ DQG GH
± D QHZ NLQHPDWLF SULQFLSOH RI PRWLRQ WUD
VSKHURVSDWLDO LQWHUDFWLRQ RI FRQMXJDWHG V
± PXOWLSDUD JHDULQJ ZLWK XS WR SDLUV RI V
± JHRPHWU\ RI WKH FRQFDYH FRQFDYH FRQWDF
FRQYH[FRQFDYH IODQN SURLOHV ZLWK PLQLPDO
DQG VOLS ZLWK UHGXFHG IULFWLRQ EHWZHHQ WK
7KHVK WKUHH LQQRYDWLYH VROXWLRQV DV D ZK
WUDQVPLVVLRQ 337 WR ZKLFK FRPSOH[UHVHDU
7R UHDOLJH WKH PDMRU LPSRUWDQFH RI WKHVK
SHUFHLYH WKH GLPHQVLRQV RI WKH HFRQRPLF
UHGXFWRQ RI WKH HGHUJ\ ORVVHV LQ WKH PHF
WKDW RI WKH JOREDO HGHUJ\ LV WUDQVPLWV
PDFKLQHV WKURXJK PHFKDQLFDO WUDQVPLVVLRQV
HIILFLHQF\ E\ RQO\ ZLOO OHDG WR WKH VDYLO
JOREDO\

, GHQWLI\ LQJ WKH DQVZHU WR RZKWRIFRPELQWDC
SHUIRUPDQFHV LQ D VLQJOH PHFKDQLFDO WUDQVFR
WKURXJKRXW WKH UHVHDFK DQG GHYHORSPHC
VXPPDULJLQJ LQ WKH IROORZLQJ ILQGLQJV
± WKH H[WHQVLRQ RI WKH UHVHDFK SRKVLH
NLQHPDWLF VWUXFWXUH. DQG FRVZLQYFKV WKURXJK
UDQJH RI WKH UHDOLJHG WUDQVPLVVLRQ UHSRUV
NQRZQ PHFKDQLFDO WUDQVPLVVLRQV
± WKH LQFUHDVH RI WKH RQHHUDQKLFYSIDFEWGHY
JHRPHWU\ RI WKH FRQFDYH FRQFDYH FRQWDFW RI
WKH UDGLL RI FXUYDWHUH
± WKH LQFUHDVH RI WKH FRQFDYH RQHHUDQKLFYSIDFEWGHY
WKH IULFWLRQDO VOLS EHWZHHQ WKH FRQMXJDW
DFFRXQW RI WKH VSKHURVSDWLDO PRYHPHQW RI W

%ULHI KLVWRU\

7KH ILUVWRU\$DEPHQWJHUUHFHVVLQRQDO SODQHW
ZLWK PXOWLSDUJLWUHG RQ 68
SULRULW\ RI DQG \$LW KUHPXOWLSHSDHG
68 \$ ZLWK SULRULW\ RI
LQYHQWLRQ ZLWK \$RRWKHG SHUIR HVVLRQDO W

PXOWLS&JUD ZHDVUHHJLVWHUHG RQ 68
SULRULW\ RI DXWKRU ,RQ %RVWDQ
7KH PRGLLFDWLRQ RI WKH JHRPHWU\ RI WKH F
WHHWK\$%IODQDQW LWV GHSHQGHHQH RQ WKH S
a=j Tr 'ZHUH IRUPXODWHG LQ WKH SDWHQW 86
WKH DSSOLFDWLRQ RI WKH 6WDWH 6HFUHW SUR
7RJHWKHU ZLWK WKH UHVHDFK DQG \$HYHORS
@ DQGS @ WKH WHFKQRORJLHV RI PDQXIDFW
QRQ VWDQGDUGLJHG IODQN SURILOHV ZHUH GH
SDWHQW IRU WKH LQYHJWUHQRIWKKHPSDFKEW
JHQHUDWLRQ E\ VSDWLDO WXPEOLQJ UROOLQJ F
FRQFDYH IODQN SURILOH 68 \$ ZDV UHJL
WKH 6WDWH 6HFUHW SURWHFWLRQ ZLWK WKH
HTXLSPHQW HQVXUH WKH JHQHUDWLRQ RI DQ L
SURILOHV ZLWK WKH SURILOH JHQHUDWLQJ WI
LQFOXGLQJ ZLWK ORQJLWXGLQDO DQG SURILO
DFFRUGLQJ WR WKH LQYHQWLRQ 68 \$ I
IURP
7KH GHYHORSPHQW RI WKH UHVHDFKHV RI WKH
LQ WKH FKURQRORJLFDQ RUGHU RI WKH\$UHVHD
ZLWK WWRJWZLWKWRQYH[FRQFDYH@ FRQDSDVFMU
IROORZHG E\ WKH>@RRFKHSHUJUDU ZLWK W
FRQYH[UH\$%LOERQDU[FRQFDYH DQ FRQFDYH FR
\$% & FRQWDFW ZLWK \$%&ZLWKWOWGHQWDEK
7KH GLVVHPLQDWLRQ RI WKH SUHFHVVLQDO V
IODQN SURILOHV REYLRXVO\ LQFOXGHG WKH H
HTXLSPHQW IRU JHQHUDWLQJ WHHWK 7KXV WK
ZKHHO WHHWK ZLWK YDULDEOH FRQYH[FRQFDY
VSDWLDO WXPEOLQJ UROOLQJ LQ WZR YDULDQW
> @ DQG ZLWK D 3SHULSKHU> SURILOH DQGLQ
SURFHGXUHV IRU WKH JHQHUDWLRQ ZLWK WKH
VWUDLJKWV WGHWKKH LQFHQDQWPHHWKDOO\ F
PXOWL D[LDO PDFKLQH WRROV > @ FKDSWHU
7KH SURFHQWR LQFOXGHV WKH JHQHUDWLRQ RI
ZKHHOV ZLWK FRQYH[FRQFDYH IODQN SURILO

%RVWDQ , 'HYHORSPHQW RI SUHFHVVLRRQDO WUDQVFR

PRGLILFDWLRQV LQFOXGLQJ WKH JHQHUDWLRQ
F\FORLGDQ DQG FLUFOH DUF IODQN SURILOH >
7KH UHVHDFK DQG GHYHORSPHQW RI SUHFHV
WKHPDWLF VSHFWUXP IURP VWUXFWXUDO FRQFH
DQG H[SHULPHQWDO DSSURDFKHV RQ SK\VLFD
IRUPV RI IODQN SURILOHV RI WKH WHHWK WR
SURFHVVHV IURP FRQVWUXFWLYH IXQFWLRQDO
WKHLU LQGXVWULDO DSSOLFDWLRQ

6\QWKHVLV DQG NLQHPDWLFV RI SUHFHVVLRRQDO

%DVHG RQ WKH ILUVW SHDZHQW RI LQYHQWLRY
NLQHPDWLF VWUXFWXUHV RI WKH SUHFHVVLRRQDO
DQG+ ILJ DQG FRPSOH[HV ZHUH FUHDWHG >
3UHFHVVLRRQDO WUDQVPLVVLRQV KDYH EHHQ GH
IXQFWLRQDO SRVVLELOLWLHV VXFK DV UHGXFH
RU WUDQVPLVVLRQ RI PRWLRQ DQG WRUTXH P
VSDFHV ILJ K. +%DVHG+ VWUXFWXUHV FRPSOH
ILJ J K RI WUDQVPLVVLRQV DQG GULYH
WUDQVPLVVLRQ UDWLRV ILJ J FDQ EH FUHDV
> @

)LJ .LQHPDWLF . +9W\ SUHFHVVLRRQD

-RXUQDO RI (QJLQHHULQJ 6FLHQFHV DQG ,QQRYPDW

7KH SUHFHVVRQDO WUDQVPLVVLRQV GHYHORS
VKRZQ LQ ILJXUHV DQG FDQ\$EHWZIRWKHGDZ

VWUDLJKQ LQFOLWCHGWK ZLWK 5 WSKHJDUV

\$'9 & \$'; 5 DQ\$E &

7KH WUDQVPLVVLRQ UDWLRV RI WKH SUHFHVVRQDO
WKH UHODWLRQV

$$L_{9}^E \frac{=J}{=E =J} IRU 937 W\SH$$

$$L_{9}^E \frac{=J =F}{=E =J =J =} IRU+ 37 W\SH$$

$$L_{9}^E \frac{=J =F =H =G}{=E =J =E =H =H =G =J =F =E =H} IRU 37 W\SH VHH ILJ$$

)LJ .LQHPDWLF . + W\SH SUHFHVVL

%RVWDQ , 'HYHORSPHQW RI SUHFHVVLQRQDO WUDQVPLVVLQRQV

7KH SUHFHVVLQRQDO WUDQVPLVVLQRQV ILJV DQG UDQJHV

SRVVLEOH 37Q\SH

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&RQFOXVORWKH SUHFHVVLQRQDO WUDQVPLVVLQRQV WKH FRQMXJDWHG ZKHHOV LQIOXHQFHV RQ WKH VHDQG NLQHPDWLFV RI WKH FRQWDFW SRLQW DQG RQ ,Q WKH VWUXFWXUDO DQDO\VLV RI WKH SUHFHVVLIRU WKH WUDQVPLVVLQRQ WKHUH FDQ EH WZR FRQIQDPHO\= LQ ZKLFK WKH GULYHQ DQG FRQGXFWLYGLUHFWRU= LV DQG ZKLFK WKH VKDIWV URWDWH LQUDWR LV UHFRPPHQGHG IRU WUDQVPLVVLQRQV ZIDQG = IRU UHGXFHU RSHUDWLQJ PRGH

)RU WKH W\SH SUHFHVVLQRQDO WUDQVPLVVLQRQ WKH WHHWK QXPEHUV > @ VKRZQ LQ ILJXUH QDPHO\ ± &RQILJXUD=WRQ =, = = =r LQ ZKLFK WKH GULYHQ DQG FRQGXFWLYH VKDIWV URWDWH LQ DGLI ± &RQILJXUD=WRQ =, = = =r LQ ZKLFK WKH GULYHQ DQG FRQGXFWLYH VKDIWV URWDWH LQ DGLI ± &RQILJXUD=WRQ =, = = =r LQ ZKLFK WKH GULYHQ DQG FRQGXFWLYH VKDIWV URWDWH LQ DGLI = = ILJ F

± &RQILJXUD=WRQ =9 = = =r LQ ZKLFK WKH GULYHQ DQG FRQGXFWLYH VKDIWV URWDWH LQ DGLI = = ILJ G

± &RQILJXUD=WRQ =9 = = = LQ ZKLFK WKH GULYHQ DQG FRQGXFWLYH VKDIWV URWDWH LQ DGLI ± &RQILJXUD=WRQ =9, = = = LQ ZKLFK WKH GULYHQ DQG FRQGXFWLYH VKDIWV URWDWH LQ DGLI

)LJXUH VKRZV WKH SUHFHVVLQRQDO WUDQVPLVVLQRQV ILJXUH RI WKH WRRWKHG SUHFHVVLQRQDO JHDU

)LJ .LQHPDWLFVURFMMKHLRQDO JHDU ZLWK EROWV DFFRU
WF

%DVHG RQ WKH DQDO\VLV RI WKH NLQHPDWLFV RI
JHDU DQG FRPSXWHU VLPXODWLRQV RQ PDWKHPD
H[SHULPHQWDO UHVHDUFK RQ SK\VLFDQ PRGHV Z
, Q WSKH WRRWKHG SUHFHVVLVRQDO WIRDUQVIXWKHWKH
HGHUJ\ ORVVHV ZKHQ RYHUFRLQJ WKH IULFWLRQ
WHHWK DQG FRQVHTXHQWO\ WR LQFUHDVH WKH
WKH FRUUDWLRQ RI WKH QXPEHU RI WHHWK RI
EH DFFRUGLQJ WR FRQILJXUDWLRQV , DQG ,, 7KH
D= = = = DQ=HQVXUHV WKH URWDWLRQ RI V
VKDIWV LQ GLIIHUHQW GLUHF=WLRRQV DQG WKH FRU
ILJ E HQVXUHV WKH URWDWLRQ RI WDG=VKDIWV
9 SUHFHVVLVRQDO JHDU=VZLMMKWXPERUDWLRFRUGLQ
E PD\ EH UHFRPPHQGHG IRU XVH LQ WUDQVPLVVL
FRQILJXUDWLRQ RI WKH QXPEHU RI WHHWK LV FKR
7KHí+ W\SH WRRWKHG SUHFHVVLVRQDO JHDUV ZLV
UDWLR= R= = DQG+ 9 W\SH ZLWK FDQ EH
UHFRPPHQGHG IRU WUDQVPLVVLRRQV ZLWK PXOWLS
DQJOH RI WKH FHQWUDO ZKHHO WHHWK
7KH FRQILJXUDWLRQV RI WHHWK QXPEHUV ,, , 9

%RVWDQ , 'HYHORSPHQW RI SUHFHVVLVRQDO WUDQVPLVVLRQ

EH XVHG LQ WKH HODERUDWLRQ RI WRRWKHG SUHJLPH EHFDXVH WKH\ LQFOXGLQJ DW DQZKWKFRQWUDWLRQ RI WKH WHHWK QXPDMHGV WR FRQVLGHUORVVHV IRU GHIHDWLQJ VOLS IULFWLRQ IRUFHV

)LJ 7KH NLQHPDWLF WRRWKHG SUHFHVVLVRQDO JHDU ZLWK WKH WKH VDWHOOLWH DQG E

&RQFOXVLRQ SUHFHVVLVRQDO WUDQVPLVVLRQV KD WUDQVPLVVLRQV NQRZQ ZRUOGZLGH RQ WKH ZLQFOXGLQJ WKH NLQHPDWLF SRVVLELOLWLHV WR FRUHJLPH

'HVLJQ RI WRRWK SUHFHVVLVRQDO JHDU

7KH SXUSRVH RI WKH UHVHDUSFKSUDQGHVLYHQRPSRHHFRQYH[FRQFDYH FRQFDYH FRQFDYH FRQFDYH GHVFULHQLQFUHDVH WKH EHDULQJ FDSDFLW\ > @ DQG WR URI WKH WHHWK LQFOXGLQJ WKH H[FOXVLRQ RI WUDQVPLVVLRQV

7KH HIILFLHQF\ RI WKHVH WZR LQWHUGHSHQGHW SHUIRUPDQFHV RI D PHFKDQLFDO WUDQVPLVVLRQ

'HVLJQLQJ WKH JHRPHWU\ RI WKH FRQFDYH FRQFDYH WKH WHHWK ZLWK WKH VPDOO GLIIHUHQFH RI WKH 5HGXFWRQ RU H[FOXVLRQ RI IULFWLRQ ZLWK UH WKH FRQMXJDWHG WHHWK

,Q WKH FRQWH[W RI WKH DIRUHPHQWLRQHG WKH FRQFDYH RU FRQFDYH FRQFDYH FRQFDYH RI WKH WHHWK DVVLJQLQJ D SURILOH LQ D FLUFOH DUF WR WKH VDWHOOLWH DQG WR WKH WHHWK RI WKH FHQWU

WKH ZUDSSHU RI WKH FLUFOH DUFV IDPLO\ ZLWK W
DQG GHWHUPLQH E\ WKH ^aSDU₁DPHW@LF FRQILJXUD
7KH NLQHPDWLF UHODWLRQV RI WKH VDWHOOLWH
WKH FHQWUDO ZKHO RI WKH SUHFHVVLHQDO WL
HTXDWLRQV VHW RXW LQ > @ ³7KH IXQGDPHQWDO
7KH RUHWLFDO HODERUDWLRQV WKH SUHFHVVLHQDO W
PHWKRGV DSSOLHG DW RFDWJH VDWHOOLWH W
,Q RUGHU WR FUHDWH WKH FRQYH[FRQFDYH FRQV
PRWLRQ ZH DGPLW WKDW WKH SURILOH R₀ WKH V
FXUYH IRU H[DPSOH LQ (RULHQDWH DOJF LQ JSIDGQW
FDOO H₀ WKH QRH SRW₀ VOLWH WHHWK > @
)URP WKH (XOHU NLQHPDWLF HTXDWLRQV WDNLQ
EHWZHHQ WKH QHQSOHV VHG E_z ZH REWDLQ WKH FR
RI WKH *RULJWKH UDGLXV R₀ WKH DEUROGLQFWR
URWDWLRQ DQJOH RI WKH FUDQN VKDIW

$$; \cdot 5FRQ \quad FRV = \sqrt{E} \quad | \quad = \sqrt{L} \quad FRV \quad 5 \quad G \quad FRVT \quad VLQ \quad VLQ$$

$$< \quad 5FRQ \quad VLQ = \sqrt{E} \quad | \quad = F/R \quad FRV \quad 5 \quad G \quad FRVT \quad \backslash$$

$$= \quad 5FRQ \quad FRV = \quad T \quad V \quad 5 \quad Q \quad G \quad VLQ \quad FRV$$

7KH RULJLQWKH UDGLXV RI WKH FLUFOH DUF ZLW
DUELWUDULO\ GHVFULEHG PRYHV RQ ⁵ZKWK XWK B
RULJLQ LQ WKH SUHFHVVLHQDO FHQWUDO W
E\ WKH FRUGLQDWHV
7KH WUDMHFWRU\ RI WKH RULJLQ R₀ HW B₀ FR B₀ Q₀ W₀
ZLWK B₀ D₀ L₀ SURMHFW₀ SHOD₀ Q₀ XWK₀ L₀ J₀ WKH UXOHV RI VS
> @ 7KXV ZH REWDLQ WKH PRYHFWRU RI WKH RUL
WKH FLURQH W₀ B₀ S₀ D₀ H₀ V₀ VHG E\ WKH /GSHHQGHQH
.QRZLQJ WKH WUDMHFWRU\ PRYHFWRU RI WKH RUL
WKH FLURQH W₀ B₀ S₀ D₀ H₀ V₀ VHG LQ WKH ERRUGLQDWH VHGHWHU
WKH SRVLWLRQ RI WKH RULJLQ R₀ W₀ B₀ S₀ D₀ H₀ V₀ VHG WRRWK SUR
WKH SURILOH RI WKH FHQWUDO ZKHO WHHWK
7KH FRQWURVSRHWHHWK RI WKH VDWHOOLWH LQ
ZKHO IRU DQ\ DQJXO B₀ S₀ D₀ H₀ V₀ VHG LV ORFDWH
UDGURXWKH FLUFOH DUF RQ WKH RULJLQ R₀ W₀ B₀ S₀ D₀ H₀ V₀ VHG
* ILJ

%RVWDQ , 'HYHORSPHQW RI SUHFHVLRQDO WUDQV

)LJ 'HVFULSWLRQ RI WKH WUDMHHFWLRKH RIDWKXIVPRIMWR
FLUFOH DUF LQ /FRSURJLQDWHHS RQ WKH SODQH

7KH IDPLO\ RI FRQWREWDSDGHGWLWKLQ D SUH
dl d S= / = UHSUHVHQWV WKH SURILOH RI WKH FHQW
1H[W WR GHVFULEH WKH SURILOH RI WKH FHQWUD
RI WKH SHHG YHFWRU RQ WKH; FRPREGLODWHVVDVH R

)LJ 'HVFULSWLRQ RI WKH SURILOH RI WKH FHQWUDO Z
9* RI WKH *RULJWH FLUFOH DUF

)RU WKLV SXUSRVH ZH GHULYH LQ WLPH HTXDWLR

∴ 5I FRQ₁ =/ = FRVI VLQ =VLQRTV ≠ = FRM =FR_{1/4}

5I VLQ VLQI FRV

< 5I FRQ₁ ≠ = FRVI FR= =VLQRTV ≠ = IVLQ =FR_{1/4}

5I VLQ VLQ VLQ

≡ 5I ≠ =FRV VLQ≠V≠Q

ZKHUHV WKH DQJXODU VSHHG RI WKH FUDQNVKDIW

7R GHWHUPLQH WKH SRVLWLRQWKIHWKHHFRQWQFWW

VXUIDFH ZH LGHQWLI\ WKHUBZDSHURSHQGDF&ODQE

YHFWRUZKLFK SDVVHV WKURXJK DQG SUKHFIRVULJQ

%RVWDQ , 'HYHORSPHQW RI SUHFHVLRQDO WUDQV

UDGLXV RI WKH FKHU FOTX DWIFR Q FID Q KEH SODQVWHQ
H[SUHVVRQ

2 * u2 & u9

ZKH D H D Q Q DUH YHFWRUV WKDW GHWHUPLQH WKH
RI WKH VDWHD D D W F L W R O W D U F D Q G U H V S H R W L Y H C
WKH SODQH ZLWK UHVSHFW WR 2, W K H F R R U G L Q D R M H W K V
ILJ

7KH YHFWRU * S U R G L X F W [S U H V V H G L Q W K H I R U P R I
WKLUG RUGHU DQG RSHQLQJ LW DIWHU WKH HOHP

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VDWHOOLWH L Q = D F W K H O F R B U G L Q D W H V & R R Q W K H D U
SODQH

\$QDORJRXVO\ ZH GHVFUZE H 2 W K H Y H F W I R Q J H T X D W L
7KH FRQWDFW SRLQW R R Q J W K D W W W W K W / D P H W L P H W R
5 WKDW LV LWV FRRUGLQDWHV VDWLVI\ LWV HTXD

; (< = 5

)URP ILJXUH ZH REVHUYH WKDW WKH DQJOH EH
UHIHUHQFH SRLQW RI W K H F R R U G L Q D W H V R I W H O F W H F D Q
WKH SRVLWRQ RI W K H F R R U G L Q D W H V R I W H O F W H F D Q
E RI WKH WHHWK RI WKH VDWHOOLWH LQ WKH FLUR

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)URP HTXDWLQJ ZH GHWHUPLQH

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LQ D Q G R E W D L Q

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DQG E\ UHSODFLQJ LQ ZH; R F E R V D L Q Q W K M H H R S
FRQWDFW SRLQW

; (N = C

ZKHUH

$$N \frac{a}{1} ; \text{\$} ; \sim^x ; <^x ; \frac{x}{4} \cdot = \frac{0}{4} / \text{\$} ; \cdot < \cdot ; \frac{x}{4} \cdot =$$

$$G \ 5 \ \text{FR} \frac{x}{4} / \text{\$} ; \cdot < \cdot ; \frac{x}{4} \cdot$$

$$N \quad N \quad \cdot = \cdot ;$$

$$G \ 5 \ \text{FR} \ G < \ ;$$

% \ VXEVWLWXWLQJ DQG LQ DQG VROYLQ WKHFRRUGLQDWH RI WKZH FRRUGLQDWH SRLQW

$$= \frac{NG \ N \ G > \ NG \ N \ G \quad N \ N5}{N \ N} / \ G \ G$$

,W LV ZRUWK PHQWLRQLQJ WKDW WKH FXUYH RI VHTXLGLVWDQW IURP WKH WUDMHFRW WKH HRU DVKHX VFRFLUFOH DUF DQG IRURDQ KHR WDDQ RYOK DQWLVKH FIPXVW EH PHW

\$IWHU VRPH WUDQVIRUPDWLRQV FRRWGH QH[S H HFD GHWHUPLQH E\ WKH UHODWLRQ

$$= \frac{NG \ N \ G > \ NG \ N \ G \quad N \ N5}{N \ N} / \ G \ G$$

7KH UHODWLRQV DQG DQG FRRUGLQDWH WKH FRQWDFWRIS WKH WWHHWK WKH VHW RI ZKLFK LQ D SURILOH RI WKH FHQWUDO ZKHO WHHWK SODFHG 7KH SUHFHVVLQRQDO JHDU EHLQJ FRQLFDO ZLWK LQWHUVHFHWG LQ WKH SUHFHVVLQRQ FHQWHU LW WHHWK LQ WKH QRUPDO FURVV VHFOLRQDQ MKURX SRLQW DQG SHUSHQGLFXODU WRLWKH SODQH

7KH < = FRRUGLQDWHV DQ FRRUGLQDWH WHHWK SURVSKHUH DUH GHWHUPLQH IURP WKH UHODWLRQV DQJOHV DQG S=/ = FRUHVSRQGLQJ WR D SUHFHVVL8VLQJ WKH UXOHV RI VSKHULFDO WULJRQRPHU\ VSKHUH ZLWK QDQV SODQH

7R GHVLJQ WKH SURILOH RI WKH FHQWUDO QDQZWKHO SODQH GH GUDZ WKH FRRUGLQDWH WKH WULJQRPHU\

%RVWDQ , 'HYHORSPHQW RI SUHFHVVLQRQDO WUDQVPL

D[L(V/ SDVVHV WKURXJK SRLQW P<WKG FRRUGLQDWH
ZH PRYH /WDRYFRH RUGLQDWHV XVLQJ WKH UHODWLRQ

$$I \frac{a}{-} \left(\left(\frac{Q}{Q^{1/4}} \right) \right) \sqrt{Q} I$$

&RQFOXVWKRQH[SUHVVLQRQV UHSUHVHQW WKH FR
FXUYH WKH IDPLO\ RI ZKLFK FRQVWLWXWHV WKH
WHHWK GHVBJQSIGDRQ WKH SUHVHVG LQ SDUDPHWU
SUHFHVVLQRQ DQWRH S+R-P

7R GHVLJQ WKH WUDMHFWRU\RI WKH FLUFOH QWF
PRYH IUR;P<WKG FRRUGLQDWHV WR WKH &DUWHV
XVLQJ WKH UHODWLRQV

$$I \frac{a}{-} \left(\left(\frac{6}{6^{1/4}} \right) \right) \sqrt{6} I$$

7KH IXQFWYRQ UHSUHVHQWV WKH SURMHFWLRQ R
WKH R*URJLVKH FLUFOH DJFDQJQ WKH ISQDQHRQ
UHSUHVHQWV WKH SURILOH RI WKH FBQWUDO ZKH
)LJXUH VKRZV WKH SURILORJUDP= R= VZKWKWKWK

SDUDPHWULF ERQILJXUDWLRQPPT ° G ° DQG
5 PP D DQG RI WKH WRZWKHGWKHS SDUDPHWULF
= = U PPT ° G ° DQG PP RI WKH
. + SUHFHVVLQRQDO UHGXFHULZLWK WKH WUDQVPL

)LJ 7KH UHIHUHQFH SURILORJUDPV RJ WKHIFLDQWKH RI WK
WRRWKHG SUHFHVVLQRQDOLJHDKWKH UHIHUHQFH PDKOWLSOLFL
H E

7KH SURILOHV RI WKH WHHWK RI WKH FHQWUDO
/ I / FRQVWUXFWHG DIWHU WKH UHODWLRQV
SUHVFULEHG LQ D FLUFOH DUF ZLWK UDGLXV

*HRPHWU\ DQG NLQHPDWLFV RI FRQFDYH FRQFDY

,Q WKH FODVVLF WUDQVPLVVLRQV ZLWK PHWUHQV
WHHWK FRQWDFW LV SUHGILQH E\ WKH FXUYH
FRQMXJDWHG WHHWK DPRQJ ZKLFK WKH HYROYHG
HSLKLSRF\FORLG WURKRLG FLUFOH DUF HWF
8QOLNH WKH FRQYHQWLRQDO RQHV LQ WKH SUHF
FHQWUDO ZKHHO WHHWK LV YDULDEOH GHSHQGLQ

Tr ' > @ FK 7KLYDUH DWORQ RQWKH JHRPH
FRQWDFW WKH VDPH JHDU VHH ILJ D E SDVVLQJ
IURP WKH FRQYH[FRQFDYH DW WKH IRRW RI WKH
UHFWLLOLQH DU WR WKH PLGGOH RI WKH WRRWK DQ
> @ VHH VXE VHFWRQV

,Q\$ WRRWKHG SUHFHVVLRQD\$ ERDUW XOLNHU DW
DQG WUDQVPLVVLRQ RI PRYHPHQW DQG ORDG RFP
IULFWLRQDO VOLS EHWZHHQ WKH IODQNV RI WKH
FRQILJX^a DWLRO ± @

7KHUHIRUH WKH FDOFXODWLRQ DQG GHVLJQ RI WKH
WR WKH FRQYHQWLRQDO JHDUV LQFOXGLQJ WKH
DOJRULWKP IRU GHVLJQLQJ WKH JHRPHWU\ RI WKH
WKH EHDULQJ FDSDFLW\ DQG WKH PHFKDQLFDO HII
7KH GHVLJQ RI WKH JHRPHWU\ RI WKH WHHWK FR
\$ VXPPDULJHV LQ WKH LGHQWLILFDWLRQ RI WK
SDUDPHWHUV GHWHUPLQDWLRQ RI WKH ORDG G
NLQHPDWLFV RI WKH FRQWDFW SRLQW RI WKH IOD
WR WKH SXUSRVH RI LQFUHDVLRQ WKH EHDULQJ
FRQWDFW

,Q > @ VXE VHFWRQ WKHUH ZHUH PHQWLRQ
EHDULQJ FDSDFLW\ DQG WKH PHFKDQLFDO HII FLH
WUDQVIRU FRQWDFW WKH PHFKDQLFDO WKH VKDSH
WHHWK RI WKH FRQMXJDWHG ZKHHOV ,W ZDV IRXC
PXOWLS^a DWLROU GHU WR UHGXFH WKH UHODWLY
ORDG FDSDFLW\ ERG WR WKH FRQYH[FRQFDYH JHR
ZLWK WKH VPDOO GLIIHUHQFH RI WKH FXUYDWXUH

%RVWDQ , 'HYHORSPHQW RI SUHFHVLRQDO WUDQV

)LJ 7HHWK SURILGHVFC FULZSVHFHVLRQDO JHDU ZL
DQG PXOWLS(

-RXUQDO RI (QJLQHHULQJ 6FLHQFHV DQG ,QQRYDW

)LJ .LQHPDWLFV DQG JHRPHWU\ RI WRRWK FRQVDFM DIUQ W
= = ZLWK = DQG ° D DQG JHDZLWK = DQG ° F

%RVWDQ , 'HYHORSHPHQW RI SUHFHVVLQRQDO WUDQVFR

,Q WKH WRRWKHG \$SUHFHVVLQRQDO JHUU ZLWK WKU
VLPXOWDQHRXVO\ JHDSHG E\ FKDQJLQJ WKH VKDS
PXOWLSOLF\ ZDV USOXENGRUWRPHWK VLPXOWDQ

SDLUV RUWHHWK SDLUV ZLWK FRQWDFW RQ
FHQWUDO ZKHHO WHHWK 7KXV WKH FRQWDFWV R
H[FOXGHG FUHDWLQJ IDYRUDEOH FRQGLWLRQV
FRQILJXFDWLRQJHJDUGLQJ WKH FUHDWLRQ RI WKH
FRQFDYH FRQWDFW ZLWK WKH VPDOO GLIIHUHQF
FRQMXJDWHG SURILOHV
,Q FODVVLFDO PHFKDQLFDO WUDQVPLVVLRQV LQ
PRYHPHQW ZLWK D FRQVWDQW WUDQVPLVVLRQ UD
SDLU RI WHHWK IURP WKH JHU WKH SUHFHHGLQJ
FRYHUDJHGHJUH

)LJ (YROXWLRQ RI WKH YDULDWLRQ RI WKH WHHWK FRQ
VLPXOWDQHRXVO\ HQJDJHG

,Q WKH WRRWKHG SUHFHVVLQRQDO JHDU VKRZQ LQ
WKH ORDG DQG IRXU SDLUV RI SDVVLYH WHHWK Q
VLGHV RI WKHDFRQWDFWRI :KHQ URWDWLQJ WKH
FRQMXJDWHG E\ FRQWDFWRI JHDU DQG WKH SDLU
QHZ ORDG EHDNLQJ FRQWDFW DQWO\ PDLQWDLQL
FDUU\LQJ ORDG

\$FFRUGLQJ WR ILJXUH HDFK RI WKH IRXU SDLUV
DQJXODU FFRUGLQDWHV H[SUHVVHG E\ SRVLWLRQL
DW WKH IHHQWHUQFUHDVLQJ IURP FRQWDFW WR
I = / = \$OO IRXU SDLUV RI WHHWK UHTXLHUHG ZL
D[LV ZLWK DQJXODU WKHGHWDUWLQJ FRRUGLQDWH
SDVVVLQJ WKURXJK WKH FRQWDFW

)LJXUH VKRZV WKH SRVLWLRQ FFRUGLQJ FFRUGLQJ
WRRWK SURILOH FRUUHVSRRGLQJ °WRN WKH SRVL

I_N ° I_N ° I_N ° DQJ ° GHWHUPLQH IUR
UHODIWLRLQ ≠ = ZKHUH ... LV WKH RUGHU QXPE
FRQWDFW 7KH UDGLL RI FXUYDWXUH RU WKH FFR
FRQWDFWDFFRUGLQJ WR > @ FKDSWHU :LWKL
JHRPHWU\ WKH GLIIHUHQFH/RU WKH GHWHUPLQH X
FDOFXODWHG E\ DOWHUQDWLQJ YDU\LQJ WKH JHR

$a_{-j} T r$
,W LV ZRUWK PHQWLRLQJ WKDW DQDORJR XV WR
SDLUV RI WHHWK VLPXOWDQHRXVO\ HQJDJHG VKR
JHDU WHHWK FDQ EH GHVLJQH FRUUHVSRRGLQJ
RI WKH FHQWUDO ZKHO DQG VDWHOOLWH E\ VKR
JHDU ZKHOV UHVSHFWLYHO\

5HODWLYH VOLS EHWZHHQ WKH IODQNV RI WKH V

7KH NLQHPDWLFV RI WKH FRQWDFW SRLQW RI WK
JHRPHWULFDO VKDSH RI WKH FRQMXJDWHG IO
FKDUDFWHULVWLFV RI WKH PHFKDQLFDO HIILFLHQ
7KH PHFKDQLFDO HIILFLHQF\ RI WKH JHDU LV WK
JHQHUDWHG E\ WKH IULFWLRQDO IRUFHV ZLWK VO
EHDULQJ FDSDFLW\ RI WKH FRQYH[FRQFDYH FR
GLIIHUHQFH RI WKHLU UDGLXV RI FXUYDWXUH
)RU WKHVH UHVSRQV WKH NLQHPDWLFV DQG WKH
JHDU ILJ DUH H[DPLQH IUR JHDUV ZLWK SDU

%RVWDQ , 'HYHORSPHQW RI SUHFHVVLQRQDO WUDQVFR

GLIIHUHQW EHWZHHQ WKHP RQO\ E\ WKH=FRUUHOD
DQG WKH DQJOH RI WKH FRQWDFWHDPRGHPHQW
JHQHUDOLJHG FRQILJXUDWLRQ FDQ EH H[SUHVVH
= T ° G ° ° U P DQG PI

7KH NLQHPDWLFV DQDO\VLVNRN WKRUHQVSDQGLQBL
SRVLWLRQLQJ DQJOHV RIIWKHRUDFQVWDEWYDQWLD
OLQHDU VSHHG RI WKH FRQSDRMLSRLOWWKH FHQ
(RQ WKH SURILOH RI WKH VDWHOOLWH WHHWK D
9_{d,c} IODQNV DQG WKH JHRPHWU\ RI WKH WHHWK F
FXUYDWXUHWKH SURILOH RI WKH WHHWK RI WKH F
WKH WHHWK RIDQGHWKDWHOGUWHH HQFLQHPDWLF DQ
WKH FRQWDFW RI WKH WHHWK LV SHUIRUPHG IF
Q PLC

7KXV LQ WKH JHDU FRUUHVSRQGZQJ ZLWVWKHFR
FRUUHODWLRQ RI WKH WDEWKWKPDEWH RI WKH
G ° VKRZQ LQ ILJXUH D LQ WKHFRQWDFW
9_c P \ 9_c P \ 9_{d,c} P \ DQG WKH UDGLXV RI F
WKH SURILOH RI WKH_NFHQWURDZKHWHW_NWK_NW_N
U P DQG WKHLU_NGLIIHUHQFH_N E

:LWK WKH LQFUHDVH RI WKH DQJXODU FRRUGLQDV
ZLWK WKH W_NHS IRU H[DPSON IURP WK_NDQW_NRODU
I ° DVVLJQHG WRNWKHFRQWDFW_NGHFLQLVK
UHFRUGLQJ NQWKRQW_NIF_N9_N (N /P DQG WKH
GLIIHUHQFH RI WKH UDGLL RI FXUYDWXU_NH RI
U P LQ WKHFRQWDFW FRUUHVSRQGLQJ WR

DQG WKH GLIIHUHQFH RIWKH UDGLLQRW_NFN_NFRQW_ND
FRUUHVSRQGLQJ_NDQG WKH FRQWDFW JHRPHWU\ RI
FRQYH[FRQFDYH WR FRQYH[FRQYH[ZLWK WKH H[
RI WKH FHQWURDZKHWHW_NWK_NF VKRZV WKH HY
JHRPHWU\ IURPFRQWDFW

)LJ 7KH OLQH DU VSHHG DW WKH QWKFVLSIRLQFH R
RI FXUYDWXUH RI WKH FRQMXJDWH \$FURVCHXQFWRQ FRIQ
= = DQG ° = = T ° G ° U PP 5 P

&RQFOXVLRQ GHILQLQJ FKDUDFWHULVWLFV RI WKH
PHFKDQLFDO HIILFLHQF\ RI WKH SUHFHVVLRQDO

%RVWDQ , 'HYHORSPHQW RI SUHFHVVLQRQDO WUDQVFR

UHIHUHQFH PXOWLSOLFWMH BILMWHUHQFHURI WKH UD
WKH JHDU WWHWRISWRKHJHRPHWULF SDUDPHWHUV
9_{DO} P \ DQG PP GSHHQGLQJ RQ WKH SUHFHVVLQRQ DO
SUHYHQWLYH GHVLJQ RI WKH FRQWDFW JHRPHW
FRQILJXUDWLRQ SDUDPHWHUV

7KH GLIIHUHQFH RI WKH GLVWDQFHGEVWZHHQHQKB
FRPPRQ FRQWDFW N IRUJHDFSRQGLQ WRIWKH SUH
DQG WKHLU SRVLWLRQZKHQWV WKH UHODWLYH V
WKH WHHWK RI WKH FRQMXJDWHG ZKHHOV VR

9_{DO} ' 6 6 6

7DNLQJ LQWR DFFRXQW WKH DERYH PHQWLRQH G V
(RQ WKH IODQN RI WKH FHQWUDO ZKHHO WHHWK

$$6 | \sqrt[3]{\frac{\$G[(\cdot \frac{\$G}{\textcircled{G}} \setminus (\cdot \frac{\$G}{\textcircled{G}})](\cdot \frac{\$G}{\textcircled{G}})}{\textcircled{G}^3}} \sqrt[3]{[(\cdot \setminus \cdot)]^w}$$

ZKHQ \] DQG DUH WKH VSHHG YHFSRFLQURKHF
D[H;V< DQG

7KH GLVWDQFH WUDYHOHGRWKHFRQWDFWODSRN
ZKHHO VDWHOOLWH LQ D FLUFOH DUF IRU WKH V
GHWHUPLQH E\ WKH IRUPXOD

$$6 | \sqrt[3]{\frac{\$G[(\cdot \frac{\$G}{\textcircled{G}} \setminus (\cdot \frac{\$G}{\textcircled{G}})](\cdot \frac{\$G}{\textcircled{G}})}{\textcircled{G}^3}} \sqrt[3]{[(\cdot \setminus \cdot)]^w} \text{GW}$$

ZKHQ \] DUH WKH VSHHG YHFWRU BQRWKHF
FRRUGLQDWH D[HV

)LJXUH VKRZV WKH YDULDWRUJHGHGELVSRLOP
(EHWZHHQ WKH SRVLWLRQGEHQHWRQGH
WKH FRQWDFWWKH WHHWK SDLUV VLPXOWDQHRXV
'6 IRU WKH WRRWKHG SUHFHVVLQRQDO=JHDU ZLW
T ° G ° U P DQG PF

)LJ 7KH 6LVWVLFHWHOHG E\ WK HFRQRJWHVWV WKH VSRVLV
ZLWK DQG DQG WKHLU 6LSUHHFHQFH RQDE JHDU °
G ° E ° U PPDG PP

&RQFOXVLRQGLIIHUHQFHIGWKWDQFHV WUDYHOHG
SRLQWV RQ WKH WHHFKVSRLODKVHVDVGDORILWKH
LQWHUHVW IRU WKH HODERUDWLRQ RI WKH WUL
·&; &9 DQG FRQFDYHFRQFDYHDFW RI WKH WHHWK
SUHFHVVLRSQDDVJZBOO DV IRU WKH VWXG\ RI OX
VXUIDFHV RI WKH WHHWK LQ K\GURVWDWLF K\GUR
ILOP UHJLPHV

*HQHUDWLRQ RI WHHWK ZLWK YDULDEOH QRQ
WXPEOLQJ UROOLQJ

7KH FUHDWLRQ RI D PHFKDQLFDO WUDQVPLVVLRQ
RI WKH WHHWK UHTXLUHV FRPSOH\ WKHRUHWLFDO
WKH ILHOG PDQXIDFWXULQJ WHFKQRORJLHV RI WR
7KH QRYHOW\ RI WKH SUHFHVVLRQDO WUDQVPLVV
IURP WZR DVSHFWV IURP WKH JHRPHWU\ RI WK
PXOWLSDUD JHDU RU FRQFDYH FRQFDYH ZLWK W
FXUYDWXUH RI WKH IODQN SURILOHV RI WKH WHHV
PRYHPHQW DQG RI ORDG EDVHG RQ WKH LQWHUFDV

%RVWDQ , 'HYHORSHPHQW RI SUHFHVVLVRQDO WUDQVFR

7KH[;] &ε DQ[;] &ε FRQYH[FRQFDYH JHRPHWU\ RI WK
PXOWLSDUD JHDU DQG FRQFDYH F[;] Q[;] F[;] X[;] Z[;] DW[;] K[;] UM
UDGLL DVVXUHV WKH JHDU ZLWK D KLJK EHDULQJ
WUDQVPLVVLVRQ RI PRYHPHQW DQG ORDG ZLWK
FRQMXJDWHG ZKHHOV HQVXUHV WKH WUDQVPLVVL
WUDQVPLVVLVRQ UDWLRV RI PLOOLRQV
,Q > @ FKDSWHU LW ZDV IRXQG WKDW LQ WKH SU
FRQWDFW RI WKH FRQMXJDWHG WHHWK DV ZHOO D
RI WKH FHQWUDO ZKHHO WHHWK YDU\ GHSHQGL
a=_J Tr '

3UHFHVVLVRQDO WUDQVPLVVLVRQV ZLWK QRQ VWDQ
LQWHUDFWLRQ FDQ EH XVHG RQO\ LQ WKH FDUH
WHFKQRORJLHV EDVHG RQ QHZ SULQFLSOHV RI WH
FRVWV DQG KLJK DFFXUDF\ RI JHDUV
,W LV ZRUWK PHQWLRQLQJ WKDW WKH PDQXIDFWXU
\$' DQ[;] ZLWK YDULDEOH FRQYH[FRQFDYH WHHWK S
H[LVLWLQJ JHQHUDWLRQ SURFHGXUHV ZKLFK UH
WHFKQRORJ\
&RQFOXV[;] L[;] Q[;] SULQFLSOH RI IRUPLQJ WKH FRYHUD
GHVFULEHG ZLWK HTXDWLRQV ZLWK WKH SODF
GHVFULEHG ZLWK HTXDWLRQV VHH ILJXUH
SURFHVV RI JHQHUDWLQJ E\ VSDWLDO UROOLQJ
UHSURGXFWRQ RI WKH JHRPHWU\ DQG NLQHPDWLF
UHDO SUHFHVVLVRQDO WUDQVPLVVLVRQ
7KH QHZ WHFKQRORJLFDQ FRQFHSWV IRU JHQHUD
SUHFHVVLVRQDO WUDQVPLVVLVRQ DUH EDVHG RQ W
DQG WKH UHODWLYH PRYHPHQW RI WKH WHHWK IU
*^{FR}_U SURFHGXUH VHH ILJXUH LW LV SURSRVHG
UHSURGXFH WKH VKDSH RI WKH FRQH WUXQN ZLWK
JHDU DQG LWV PRYHPHQW UHODWLYH WR WKH V
LQWHUDFWLRQ RI WKH WHHWK ZLWK VSKHURVSDWLF
WKH HODERUDWLRQ RI WKH WHFKQRORJ\ IRU JHQH
DOVR WDNHQ LQWR DFRXQW WKH REVHUYDQFH RI
UHJDUGLQJ WKH FRQWLQXLW\ RI WKH PRYHPHQW W

-RXUQDO RI (QJLQHHULQJ 6FLHQFHV DQG ,QQRYDW

)LJ 3URFHGXUH IRU JHQHUDWLQJ WHHWK ZLWK YDULDEO
SURILOHV E\ VUROOLQJ ZLWK WKH W

)LJ *^{GL}_U JHQHUDWLRQ SURFHVV RI WHHWK ZLWK FRQYH[
WXPEUROOLQJ ZLWK WKH WRRO RI

%RVWDQ , 'HYHORSPHQW RI SUHFHVVLQRQDO WUDQVFR

,Q FRPSOLDQFH ZLWK WKHVH FRQGLWLRQV WKHUH
JHQHUDWLRQ RI WHHWK E\ VSDWLDO WXPEOLQJ UH
*^{FRQ}_{UV} ILJ *^{GLYF}_{JV} ~~ILJ~~ WK WKH WRRR SHULSKHUDO SUR
PRWLRQ ILJ ZLWK D IL[HG SRLQW LQ UHODWL
ZKHHO

)LJ 3URILOR*^{FRQ}_{JV} ~~ILJ~~ SURFHGXUH RI WKH WHHWK S
WKH ^{FRQH} WUXQN' VKDSH ' PRWLRQ ~~ILJ~~ WKH WHHWK S
UHVSHFWLYH ^{FRQ} ~~ILJ~~ DWK V\WHP WRRWK SURILOH V

)LJXUH VKRZV WKH YDULDEOH SURILOHV RI WKH
E\ VSDWLDO WXPEOLQJ UROOLQJ ZLWK WKH WRR
HODERUDWLQJ WKH ^{FRQ} ~~ILJ~~ ^{GLYF} ~~ILJ~~ UROOLQJ
WHHWK SURILOH E\ WXPEOLQJ UROOLQJ ZLWK WKH

ZDV GHVFULEHG WKH WUDMHFWRU\ RI WKH FRQW
FRQWRXU RI WKH WRRO RI WKH FXWWLQJ HGJH ZI
PDQXIDFWXUH ZKHO E\ UHSURGXFWLRQ RI WKH
JHDU DW D SUHFHVLRQDO F\FOH 7KXV WKH PDW
SURFHVV E\ VSDWLDO WXPEOLQJ UROOLQJ ZLWK
ZKLFK IXOO\ UHIOHFWV WKH FRQWDFW JHRPHWU\
WHHWK IURP WKH UHDO SUHFHVLRQDO WUDQVPLV

\$SSOLFDWLRQV RI SUHFHVLRQDO WUDQVPLVVLR

3UHFHVLRQDO WUDQVPLVVLRQV GXH WR WKHLU
FRQVXPHUV RI GULYH PHFKDQLVPV IRU WKH WU
PRYHPHQW DQG ORDG ZLWK PHGLXP DQG ODUJH
JHQHUDO SXUSRVH GULYH PHFKDQLVPV WR VSHFL
H[WUHPH WHUHVWULDO FRQGLWLRQV LQ YDFXP
DXWRPRWLYH LQGXVWU\ UREXWLFV KLJK SUHFLV
WHFKQRORJLFDO HTXLSPHQW HWF > @
7KH DUHDV RI XVH RI WKH SUHFHVLRQDO WUDQV
NLQHPDWLF DQG IXQFWLRQDO DGYDQWDJHV GXH
FRQFDYH FRQWDFW RI WKH WHHWK WKH PXOWL
PRYHPHQW ZLWK D IL[HG SRLQW RI WKH ZKHO VDV
,W LV ZRUWK PHQWLRQLQJ WKDW IRU WKH PDQXI
SURGXFW VXFK DV SUHFHVLRQDO WUDQVPLVVLRQ
PHWKRGV RI UHVLVWDQFH FDOFXODWLRQ DQG JXL
DFFRXQW WKHLU FRQVWUXFWLYH NLQHPDWLF SDU
WHFKQLFDO WHFKQRORJLFDO GRFXPHQDWLRQ RI
DQG RI PHWKRGV RI HYDOXDWLRQ FRQWURO RI W
FRPSRQHQW SDUVV 7KH XVHU RI WKH WUDQVPLV
FKDUDFWHULVWLFV LQ WKH IRUPDW RI WKH WH
SHUPLVVLEOH RSHUDWLQJ FRQGLWLRQV WKH WHF
WKH SURGXFW DV D ZKROH HWF
3UHFHVLRQDO SODQHWDU\ WUDQVPLVVLRQV DUH
WUDQVPLVVLRQV ERWK E\ WKH XQLTXH FRQVW
SUHFHVLRQDO JHDU DQG WKH FRQWDFW JHRPHW
SULQFLSOH RI PRWLRQ WUDQVIRUPDWLRQ DQG WU
WKH UHVHDUFK GHVLJQ PDQXIDFWXWLRQ HPDHWLQJ
SUREOHPDWLF DSSURDFKHV ZHUH UHTXLUHG IR
FRQVWUDLQWV DQG UHFRPPHQGDWLRQV VXEVTX
HLWKHU DV GLVWLQFW SURGXFWV RU ZLWKLQ WKH
EDVHG RQ WKH SUHFHVLRQDO WUDQVPLVVLRQV >
,Q WKLV FRQWH[W EDVHG RQ WKH IXQGDPHQWDO V
RI WHHWK JHQHUDWLRQ ZLWK QRQ VWDQGDUGL]H
SURLOH WKHUH ZHUH

± GHVLJQHG SUHFHVLRQDO DQG JHRPHWU ZHUH ZSRQWWU

%RVWDQ , 'HYHORSHPHQW RI SUHFHVVLQRQDO WUDQVFR

DQG LQFOLQHGZLWKWKHDUV ZLWK FRQSHJFRQFDY
FRQFDYH FRQFDYH FQWDFQZLQFQVWGHG WJKW
± GHYHORSHG QHZ WHFKQRORJLHV IRU JHQHUDWLQJ
QRQ VWDQGDUGLJHG SURILOHV ZLWK WSKHUWVFRU
SURILOHGGLQ FQDFQDFQOWL D[LDO PDFKLQ
QXPFULFDO FRQWURO
± GHYHORSHG WKH PHWKRGV RI HQJLQHHSQJ FDO
\$DQ\$E WDNLQJ LQWR DFRXQW WKH FRQVWUXFWL
JHDU RI WHHWK ZLWK FRQYH[FHQHFDYFRQ
FRQFDYH FRQFDYDFWDFW ZLWK VVUDZLJKWKVLFVWQ
WHHWK
± V\QWKHVLJHG RYHU 9 NLQHPDWLF DQG FRPELQH
± HODERUDWHG WKH PHWKRG RI HYDOXDWLRQ D
PDQXIDFWXULQJ WKH SUHFHVVLQRQDO JHDU
± GHVLJQHG PDQXIDFWXUHG DQG H[SHULPHQWDO
DQG DFWXDWLRQ PHFKDQLVPV EDVHG RQ SUHFH
DSSOLFDWLRQ DUHDV
ORVW DSSOLFDWLRQV EDVHG RQ SUHFHVVLQRQDO W
SDWHQWV DQG KDYH EHHQ GLVVHPLQDWHG LQ
JUDQWV LQ WKH ILHOG RI UHVHDFK GHYHORSHP

5HIHUHQFHV

- > @%RVWDQVPSUHFHVVLQRQDOHQHFDYDFPHQGHDFQO %RQV
2IILFQWLL S,6%1
- > @%RVWDQVPLVLL SUHFHVVLQRQDOHQHFDYDFPHQGHDFQO DFWXO
%RQMLFQWLL S,6%1
- > @hklZg BKha^Zgb_ ieZg_IJzgh ij_p_kkbhgguo i_j_^Zq k fgh]hiZ
>Kl >hdlhjkdzY ^bkk_jlZpby 'U KDE Fhkdh\kdbc =hkm^Zj
Mgb_jkb_l bf G ;ZmfZgZ Fhkd\Z Lhf klj Lhf ijbeh`_gb
> @hklZg Blj:p_kbhgguo i_j_^Zqb k fgh]hiZjgWVZpKLQxb S
,6%1
- > @hklZgB : AZp_ie^gij_p_kkbhgguoZ6WVZKLQDX S,6%1
- > @%RVWDQJKHUXWFR OD]XUXDFQO \$QWRORJLD LQYHQOLLORU
SODQHWDUH SUHFHVVLQRQDOHQHFDYDFPHQGHDFQO HQWGRPHQVISHQFMDU
FRPSXWHDFWVQGXVWVLDQHQHFDYDFPHQGHDFQO %RQMLFQWLL S
,6%1
- > @%RVWDQGHQBWHHQWQBLQ%RQMLFQWLL S ,6%1
- > @LOGKDEHQDLFDO JHOUJLWHQW QU
- > @Gh\bdh\ FmEqZlu_i_j_^Zqb Z IZd`_ dmeZqdh\u_f_oZgbafu k
kbkl_fhc aZp_ie_lgbyb^ &&&3 <